UNDERGROUND WATER RESOURCES OF IOWA

BY

W. H. NORTON AND OTHERS

UNDERGROUND WATER RESOURCES OF IOWA

INTRODUCTION

BY W. H. NORTON.

SCOPE OF THE WORK

The investigation of the underground water resources of Iowa was planned and carried out along three lines. The artesian waters of the state were studied by W. H. Norton, the waters of the drift and country rock by Howard E. Simpson, O. E. Meinzer and a number of assistants, and the chemical and industrial qualities of all ground waters by W. S. Hendrixson. Three reports were therefore submitted for publication. It was later decided, however, to publish these in a single volume. In the editorial recasting thus made needful the three reports have been combined, so that several chapters are now composed of excerpts taken from the work of two or more writers, but throughout the volume each writer is responsible for all statements respecting his allotted field of investigation. In each of the county reports data as to the artesian wells of the district and forecasts of artesian conditions for towns not now supplied with deep wells have been inserted from the report of the senior author.

The line of demarcation between artesian waters and waters of the drift and of the country rock—that is, the rock which outcrops at the surface or immediately underlies the drift—though not everywhere exact, is fairly definite and was placed where it would best subserve the uses of the public. The artesian waters of the state, except some of minor importance, rise from a few related formations of early Paleozoic age. These formations underlie practically the entire state and form a well-defined artesian system. The water beds or aquifers of this system are as a rule readily distinguished from those of the country rock as well as from those from the drift, but in one or two of the northeastern counties of the state the artesian aquifers approach the surface and might be included in the country rock.

In the investigation of the waters of the drift and of the country rock, the county was made the areal unit, and each county in the state was visited and studied. The officials of each town were asked to contribute the facts as to the municipal water supply. From the well drillers were procured data of great value as to the type of wells in common use, their depths in different localities, the materials they passed through, and the sources from which they drew their waters. As less than a week could be given, on the average, to each of the 99 counties of the state, the investigation was necessarily far more cursory than could have been wished. Fortunately the Iowa Geological Survey had nearly completed its areal work with the county as the unit, and thus a large amount of material was at hand relating to the geologic conditions which control the distribution of ground water, the topography of the state, and the structure and composition of the country rock, and of the Quaternary deposits (ground moraines of successive ice invasions with their outwash sands and gravels and interbedded deposits of interglacial epochs). All this material, both published and unpublished, was generously placed at the disposal of the writers by the late Dr. Samuel Calvin, director of the Iowa Geological Survey, and it has been very freely drawn upon in each of the county reports.

OBJECT OF THE INVESTIGATION

The need of the scientific investigation of artesian waters is obvious to all. Many of these deep zones of flow lie far below the surface and below the sources that supply the common wells. The local well driller can not be expected to know either the quantity or the quality of artesian waters or the depth at which they can be reached. Town councils in considering municipal supply often send committees to the nearest towns which have deep wells to obtain such facts as may throw light upon the local problem. Information thus gathered may be useful or it may be misleading; it is always insufficient and inconclusive. There is needed the skillful interpretation of data collected from a wide area, a knowledge of the geologic structure and acquaintance with the distribution and movements of deep waters. For house wells in towns, and for common farm wells, the knowledge of local conditions held by the well drillers of the district is ordinarily sufficient. Yet even here a scientific knowledge of general as well as local conditions often makes it possible to suggest new and better sources of ground water or new and better methods of utilizing those now in use.

The object of the investigation, whose results are here presented, is to furnish to each community so far as possible deductions made from the entire body of facts obtainable, showing whether artesian water can be found at that locality, at what depths it may be reached, through what formations the drill must pass, what mineral compounds—healthful or harmful—the water is likely to contain, how high it will rise, how large will be its discharge, and how such a supply will compare in cost, purity, permanence, and general availability with that from other sources.

COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

So far as the investigation concerns artesian waters, it has been carried on jointly by the United States Geological Survey and the Iowa Geological Survey. The State Survey began this investigation at the time of its inception, the work being under the charge of W. H. Norton. The earlier results are published in its annual reports.[1] Since 1896 the Iowa Survey has continued to gather data and to furnish to towns, corporations, and individuals all obtainable information relating to deep wells, together with forecasts of local artesian conditions. The cooperation between the state and national surveys has resulted in a more thorough investigation.

In the present report free use is made of all material gathered under the direction of both surveys. It seems desirable to col-

[1] Ann. Rept. Iowa Geol. Survey, vol. 3, 1893, pp. 169-210; vol. 6, 1896, pp. 115-428

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lect in one report the entire body of data relating to the subject as a basis for the deductions which may be drawn therefrom.

GEOLOGIC INVESTIGATION OF WELLS

MEANS OF INVESTIGATION.

The distribution and the quality of artesian waters are so intimately connected with geologic conditions that their profitable study must concern itself first with the attitude, the texture, and the composition of the deep rocks from which the waters rise. In a general way much may be inferred as to these features from the character of the formations where they outcrop, for here their thickness may be measured and their various physical characteristics may be observed. The dip or inclination of any terrane gives some clue to the probable depth at which it may be found at a given distance from the outcrop. But in an area so large as Iowa formations that dip below the surface may be expected to thicken or to thin, to pinch out, to be replaced by other formations which may have no outcrop, to change their chemical composition or their texture, and to be affected by various upwarps and downwarps which may have no surface expression.

For all these reasons the investigation of the deeper water beds must be based not only on the surface geology of the state but also on all geologic facts obtainable from drill holes as to the strata through which they have passed as set forth in the logs of drillers and the samples of the rock cuttings of the drill. From these data the attempt is made to correlate the strata penetrated by any well with known terranes outcropping elsewhere and found in other wells, to ascertain the geologic formations to which the strata belong, and thus to construct a geologic section at the locality of the well to the depth of the boring. By connecting the sections of different wells in different parts of the state, cross sections may be had which show the geologic structure of many parts of the area to depths of 2,000 and even of 3,000 feet, and which indicate the depth to which new wells in the area must be sunk to reach the deep-lying water beds. Plates V to XVIII supply examples of such sections in different parts of the state.

AVAILABLE DATA.

The data on which a geologic investigation of deep wells must rest consist of records made and samples of drillings collected when the well was put down. Necessarily they are largely second-hand and are incapable of verification. A report such as this deals with thousands of statements and observations made by many individuals, and the writer can do little except to determine the lithologic character of deep-well drillings, and in drawing inferences from these he must accept the reports of others as to the thickness and location of the strata which they represent. Fortunately, many owners of deep wells and many other citizens realize the scientific and practical value of the facts which can be obtained when a well is being drilled and at that time only, and these persons have placed on record many valuable data as to diameters of the bore and casings, fluctuations of water in the tube, depth, discharge, and head of water horizons, and have obtained both the driller's log and samples of the drillings. In practically every place where such data have been gathered and preserved they have been placed at the service and disposal of the surveys. Unfortunately, of many wells little or nothing, except the existing head, discharge, and quality of the water, is known or can ever be known. In many parts of the state the writer is quite in the dark as to artesian conditions and is unable to make reliable forecasts for towns desiring to sink deep wells, not because no deep wells have ever been drilled within the area, but because when they were put down no record was made of the essential facts.

SAMPLES OF DRILLINGS.

COLLECTION AND STORAGE.

Since the beginning of this investigation a special effort has been made to obtain full sets of samples of the drillings of the deep wells of the state, and it is on these samples that the geologic part of this report is largely based. Where such samples are taken directly from the slush bucket and labeled at once with the exact depth from which they were drawn, they form the most authentic record possible of the strata penetrated.

When thus taken, at intervals not exceeding 10 feet. and at every "change" in the strata, they afford a lithologic record and section inferior in value only to an exposure of the edges of the strata in an outcrop. Such reliable data have been obtained from an exceptionally large number of Iowa deep wells.

The value of sets of cuttings from some wells has been impaired by the neglect of precautions which should be obvious. Thus, if the samples are taken only at every "change" of the strata, it is left entirely to the judgment of the workman who empties the contents of the slush bucket to decide whether or not there has been any change. Several hundred feet of limestone, including two or more geologic formations, may be represented by a single sample. The depth is not always carefully taken, and remeasurements of the well on completion have shown that the driller's estimates of depth placed on samples or in the log were incorrect. If, however, the inaccuracy affects all depths about alike little serious error is likely to result.

Some samples of drillings seem to have been labeled from memory after a considerable lapse of time. This fact affords an explanation of the reported occurrence of drift clays 1,000 feet and more below the surface, and perhaps also of the occurrence of several samples of nonmagnesian limestones of Platteville facies below the Saint Peter sandstone. Some samples seem to have been scraped up from the ground instead of being taken in some clean receptacle immediately from the sand pump. The cinders which may be included are easily disregarded, but the admixture of chippings from higher levels is serious. In one or two extreme cases it seems probable that at the completion of the well the workmen went over the outwash from the slush bucket, dug up a sample here and there, and labeled it according to their recollection. But even such a record may be of value if nothing better is available.

The samples collected under the direction of the United States Survey were sent to Washington in stout canvas bags provided with labels and were there transferred to wide-mouthed glass bottles with screw aluminum covers. In the collection made earlier for the Iowa State Survey most of the samples were taken directly from the slush bucket, put into empty cigar boxes, labeled, and shipped to the writer at Mount Vernon, where they were transferred to wide-mouthed glass bottles for permanent preservation, each sample being thus kept separate and accessible. Some of the samples presented to the survey had been mounted in long glass tubes, in which the chippings of any terrane are supposed to occupy a space proportional to the actual thickness of the terrane. Such a method of mounting has a certain advantage for purposes of exhibition, but its disadvantages are so great that it must be unqualifiedly condemned. The drillings from different strata settle and tend to mix. They can not be taken from the tube for study, and no adequate inspection can be made through the glass. Sooner or later the long tube is sure to be broken and the record of the geologic section is irretrievably lost.

Drillings should not be washed. When the drill is working in a pure limestone washing does little harm, for it removes only the fine flour of the stone, whose quality is fully represented in the larger chippings. But with some marls and shales and with clayey sandstones the removal of the finer material in washing leaves a residue far from representative of the rock. In some sets certain samples had been washed and others not, thus making error possible in the determinations, except where the treatment to which the cuttings had been subjected was indicated on the labels or could be told by inspection.

For all scientific purposes samples should be taken directly from the sand pump at every 5 or 10 feet, at the end of a cleaning out, and at every change of stratum. They should be placed, unwashed, in wide-mouthed bottles or glass jars (one to four ounce bottles are large enough) and plainly and accurately labeled in india ink with the names of the town or other location and of the owner, the date, and the depth from which each was taken.

STUDY OF SAMPLES.

PETROGRAPHIC EXAMINATION.

The drillings were studied petrographically as an aid in identifying from well to well, the strata from which they came. With some samples a simple inspection was sufficient, but, as a rule, this inspection was supplemented by other tests. Under polarized light in the field of the petrographic microscope the minerals making up the meal or flour of the drillings were generally readily determined and their relative proportion in the rock was roughly indicated by their proportion in the microscopic field. Crystalline silica, flint and chalcedony, gypsum and anhydrite, glauconite, pyrite, and calcite—to mention only common minerals of the sedimentary rocks—were thus distinguished. The microscope was used also in determining the texture of such rocks as oolites, fine-grained sandstones composed of angular quartzose particles, sandstones of grains of crystalline quartz of various degrees of rounding and assortment, and sandstones whose grains have been enlarged by secondarily deposited silica. Limestones were tested with weak cold hydrochloric acid, free effervescence indicating a small percentage or total absence of magnesium carbonate, and a slow and feeble effervescence a high percentage of the same carbonate, unless attributable to siliceous or other impurities. Residues after digestion in strong acid determined the argillaceous and siliceous contents of impure limestones. The relative amount of magnesium carbonate in some limestones was roughly estimated after a solution in hydrochloric acid had been neutralized with ammonium carbonate and treated successively with ammonium oxalate and hydric disodic phosphate. Through the kindness of Dr. Nicholas Knight, professor of chemistry in Cornell College, Iowa, the services of several of his advanced students were placed at the disposal of the writer, and a number of quantitative analyses of samples of terranes of special interest were made in the chemical laboratory of that college.

POSSIBILITIES OF ERROR.

Mention should be made of certain possibilities of error in any determination of the nature and thickness of the rock by means of drillings.

The most serious of these errors is due to fewness of samples. Where, as in some deep wells, samples are taken at regular intervals of 100 feet, little indeed can be determined as to the geological succession. Where samples are taken at irregular or considerable intervals, it may be naturally assumed that each sample represented to the driller a stratum of homogeneous rock and that each sample was taken at the change and thus designates the summit of its own terrane and the base of the terrane above it. This assumption may or may not be correct. Any such sample may possibly be taken midway or at any other point within a terrane instead of at its top, and the assumed thickness of one terrane may be as much too little as that of the next terrane is too great. This source of error is avoided when a sample is labeled not only with its own depth but with the upper and lower limits of the stratum which it is supposed to represent. In the columnar geologic sections of this report the uncertainty attaching to the thickness of a terrane from this cause is indicated by drawing the terrane over the area of uncertainty as a right triangle with apex downward. (See Tipton section, Pl. X.)

Another source of possible error lies in the fact that the contents of the slush bucket may not correctly represent the rock in which the drill is working. Along with cuttings from the contiguous rock are fragments of other and higher strata. The vibration of ropes and rods and the lifting and lowering of the drill and other implements may detach pieces of rock from any higher stratum. Caving shales and incoherent sandstones furnish a large admixture of shale and sand to the cuttings at the bottom of the drill hole. Thus black coaly shale from the Coal Measures (Pennsylvanian) may be recognized in otherwise clean limestone chips of the Mississippian or inferior terranes; the fossiliferous green shale of the Platteville is seen mingled with cuttings in the dolomites of the Prairie du Chien stage; and the Saint Peter and Jordan sandstones contribute a large arenaceous content to the cuttings of the dolomites below.

Where strata of different character alternate at short intervals the mingling of cuttings makes the determination of the rocks peculiarly difficult. Drillings from Ordovician and Cambrian strata below the Saint Peter in many places contain a mixture of rolled quartz grains and chips of dolomite, and it may be a delicate question to decide whether the sand is wholly foreign, having fallen in from water-washed, loose, overlying sandstones, or whether it is more or less native—that is, whether the sample represents either a pure dolomite on the one hand or an arenaceous dolomite or a calciferous sandstone on the other. If it is decided that some of the sand is native to the stratum, it still remains to be discovered whether the sand is disseminated through the dolomite or exists in thin interbedded layers. In some samples an interbedded sand grain or mold of sand in some larger chips of dolomite may decide in favor of dissemination.

In some drillings material fallen from above may be distinguished by its lithologic nature or by the size or shape of its fragments. The dislodged pieces from the sides of the drill hole should as a rule be larger than drill cuttings and of different shape. Fragments of easily worn shales fallen from overlying beds soon assume a rounded form. But in many wells, as, for example, where fragments from above have themselves been cut into chips by the drill, these tests are not decisive and the real nature of the bottom rock must be left in some doubt. To keep distinct the facts observed in the study of well drillings from the inferences drawn by the observer, a complete statement of the composition of the drillings should be given as well as an opinion as to the character of rock which they represent.

CORRELATION OF ROCK FORMATIONS.

The methods in correlation and the degree of certainty to be attained must next be considered. If an unbroken series of drillings from the top to the bottom of the well has been obtained, by what methods can the different rocks thus represented be assigned to known formations?

FOSSILS.

The occurrence of a series of fossils in a given terrane—the sure means employed by the geologist whenever possible in his correlations—is lacking in well records and samples. The drill cuts and crushes the harder rocks to fine meal or powder and the softer to small chips. It is the rarest of good fortune that the drill leaves any fossil unbroken into unidentifiable fragments. The smaller the fossil the greater its chances of escape. The minute tests of the foraminifer Fusulina are sometimes obtained intact in considerable numbers from certain strata in the Coal Measures. Rocks fallen from higher strata in the drill hole give fragments of considerable size, and when these are fossiliferous and their own horizon can be determined by lithologic identity, they are of the greatest value. Thus the caving green shale of the Platteville is in places highly fossiliferous and its fragments, along with bits of Ordovician brachiopods characteristic of the horizon, are often brought up when the drill is working in the subjacent strata. But such fossils will be a source of the gravest error if it is assumed that they belong to the same formation as that of the cuttings brought up with them from the bottom of the well.

LITHOLOGIC SIMILARITY.

The lithologic method employed by geologists in the field in tracing a terrane from point to point is by no means infallible when applied in studies of deep wells, but it is used when other methods are lacking. Certain terranes exhibit the same well-defined lithologic characteristics over a large part of Iowa and adjacent states. The coaly shale of the Pennsylvanian can hardly be mistaken for the calcareous (mud rock) shale of the Maquoketa, nor can either be confounded with the glauconiferous shales of the Cambrian. The white crystalline encrinital limestone and the cherts and oolites and geodiferous beds of the Mississippian are diagnostic, and the same is true of the arenacous cherty dolomites of the magnesian Prairie du Chien stage. The presence of anhydrite or gypsum in certain beds has been used to correlate rocks in widely separated wells.

The magnesian carbonate content of limestones can be used as a means of correlation, but must be used with care. Thus, so far as known, from the Shakopee dolomite down all limestones throughout the state are thoroughly dolomitized. But above the Shakopee the changes in the magnesian content in the same terrane may be rapid and complete. Thus at Dubuque the Galena is a dolomite, but at Manchester, forty miles west, a deep-well section finds it wholly of ordinary limestone. Similarly, some of the Devonian limestones of east-central Iowa pass into dolomites in the northern counties.

The lithologic nature of a terrane may be expected to change over so broadly extended an area as the state of Iowa. One formation may thin and disappear and give place to other formations of the same series. Thus the Niagaran dolomite of northeastern Iowa apparently gives place to Silurian sandstones or sandy limestone in southeastern Iowa; and gypsiferous beds, perhaps of Salina age, appear in deep wells at stations as far separated as Mount Pleasant, Des Moines, Bedford and Glenwood. An entire system may disappear; for example, the Silurian in the extreme northeastern parts of the area occupied by the Devonian in Iowa.

Lithologic similarity may only exceptionally be used as the sole means of correlation. It is a belief as mistaken as it is prevalent that a geologist can identify a formation simply by means of the physical characteristics of its rocks. In the study of deep wells this means should be used only with the greatest care and in combination with other and better methods.

ORDER OF SUCCESSION.

A third means of correlation is that of order of succession. The terranes of Iowa, for example, do not occur haphazard. They were laid down in a definite order during the long ages of geologic time and for the most part on the floors of ancient seas. The oldest is therefore found at the bottom and the most recent at the top, the strata having suffered no inversive deformation. The application of this method of correlation may be illustrated from the general columnar section of Iowa (Pl. II), in which the formations are arranged in the due order of their succession. It is plain that on the areas of outcrop of the Silurian the first heavy shale which the drill encounters must be the Maquoketa. In the Mississippian area a heavy shale found near the surface may be identified as belonging to the Kinderhook, and the Maquoketa will be reached only after passing through the intervening Devonian and Silurian limestones. In the Pennsylvanian area another and still higher body of shales belonging to the country rock is first penetrated and the Maquoketa becomes the third heavy shale bed in the descending series.

DIP OF STRATA.

A fourth aid in interpreting the drillings is the known dip of the strata. A glance at any of the geologic sections of the state, such as that shown in Plate XI (along the Chicago & North Western railway from Clinton west), shows a general westward downward slope to all terranes. The second body of shale at Belle Plaine may be recognized as the Maquoketa, not only by lithologic similarity to the limy shales of that formation over its outcrops to the northeast and by its position in the series, but also by the fact that it occurs at about the depth to which the known westerly dip of the strata would carry it from its known position at Cedar Rapids.

Local exceptions to prevailing dips may be expected anywhere. Upwarps and downwarps, sags and swells, thickenings and thinnings may bring any formation nearer to or farther from the surface at a given point than would be expected. Thus at Ames (see Pl. XI) an upwarp of the entire body of strata brings each formation higher than the position which would have been deduced from the general dip. In southeastern Iowa also the dip of the surface formations is found reversed in the deeper terranes.

DIFFICULTY OF DEMARCATION.

In some deep-well sections insuperable difficulties are found in drawing the boundaries between adjoining terranes. No attempt has been made to discriminate the limestone of the Kinderhook stage from the limestones of the Osage stage (Burlington and Keokuk) which rest upon it nor the limestones of the upper part of the Maquoketa shale from the Silurian limestones which they underlie. Upper Devonian shales can not be separated with any certainty from the shales of the Kinderhook where the two are in immediate succession. With increasing distance from the outcrops of Devonian and Silurian limestones and with a changing facies in each it becomes in places impossible to draw any sure line between them. It must be understood, therefore, that in the interpretation of the sections the assignment of formations is not offered with the confidence of the field geologist. In many of the sections there may be a close approach to certainty; in others the reference is made from scanty data and on some slight turn of the scale of evidence. Realizing the nature of the data dealt with, the meager, second-hand, and sometimes untrustworthy evidence at hand, the difficulties of interpretation, and the possibilities of error, the writer submits his tentative conclusions in a spirit far removed from any dogmatism.

FORECASTS.

Information is often sought by cities, officials, and representatives of railways and other corporations and by private citizens as to probabilities of an artesian supply in their localities. In response to such requests many forecasts have been made as to the depth at which artesian water may be found, its pressure, quantity, quality, and availability for specific uses. To make this report as helpful as possible, forecasts have been made for all the towns of the state whose population indicates that an artesian supply may be needed, and in which the artesian field has not been already fully exploited. These forecasts will be found in the county descriptions.

In using these forecasts as a basis for estimating the depth to water-bearing strata at any given point, it must be remembered that many of the data on which they rest are scanty, some are conflicting, and others are no doubt erroneous. Estimates as to the depth to water beds necessarily assume uniform degree of dip and uniform thickness of strata over given areas, whereas in fact the strata vary in thickness from place to place and are affected by local upwarps and downwarps that tend to bring them nearer to or farther from the surface than would be computed on the assumption of an unvarying dip. The information given must not be used as if it had the exactness of calculations based on accurate data.

Nevertheless enough is known of the attitude and nature of the deeper rocks of Iowa to permit forecasts that may be of considerable value and perhaps sufficiently close for the purpose for which they are made. The degree of approximation which the data permit is evident by comparing forecasts already made with the facts afterward disclosed by the drill. Thus at Osage (Pl. VII) the Saint Peter sandstone was predicted at 700 to 750 feet from the surface and was found at 715 feet; at Charles City (Pl. VII) the same formation was forecast at 800 feet and was found at 780 feet; at Fort Dodge (Pl. VI) it was forecast at 1,300 to 1,500 feet and was found at 1,408 feet; at Waterloo (Pl. VI) it was forecast at 835 feet and was found at 815 feet; at Bloomfield it was forecast at 1,230 feet and was found either at 1,190 or, more probably, at 1,445 feet, the records of the well being very incomplete. At Mount Pleasant (Pl. XIII) the Saint Peter sandstone was found within 57 feet of the predicted depth.

How far local deformations, entirely unknown before the drilling of a well, may cause an error in forecast is indicated by the deep well at Ames. No predictions were made, but if it had been assumed that the Saint Peter had the same dip west of Cedar Rapids that it is known to have east of that city, the estimates of its depth at Ames would have been 250 feet too low, as the drill disclosed a local upwarp which brought the Saint Peter that far above its normal place (Pl. XI). At New Hampton (Pl. V) the Saint Peter was found 150 feet below where it would have been expected and predicted on the assumption of an uniform southward dip from Mason City to Ackley. In southwestern Iowa, where data are exceedingly scanty, the base of the Pennsylvanian at Bedford (Pl. XVIII) was forecast at 140 feet below sea level. The base of the Pennsylvanian shale was, indeed, found at 82 feet below sea level, but the intervention of a heavy sandstone, which probably should be classed with the Pennsylvanian, brought the base of the latter to 240 feet below sea level (see fig. 6.) The water horizons of the heavy magnesian limestones of this area were predicted to occur not more than 900 feet below sea level, and were found at Bedford at 850 feet below that datum. Contracts for artesian wells should make provision for drilling at specified rates for several hundred feet beyond the supposedly necessary depth.

ACKNOWLEDGMENTS.

The writer is greatly indebted to the courtesy of artesian contractors and drillers who have generously placed at his service the well logs made by their foremen as the work was in progress. Unfortunately the records of one large firm, which

has done much work in the state, were destroyed some years ago by fire, and some other firms seem to have preserved few or no data as to the wells which they have drilled. The opinion of the foreman as to the character of the strata in which the drill is working is always of value, for he has means of inference as to the strata in the "chuck" and in the wear of the drill as well as in the character of the drillings brought up in the slush bucket.

CHEMICAL INVESTIGATION OF WELL WATERS

BY W. S. HENDRIXSON.

SCOPE OF INVESTIGATION.

In the investigation of the quality of Iowa ground waters the practical aim has been kept in view. No attempt has been made to find exceptional waters containing uncommon mineral matter or common mineral constituents in uncommon proportions. The object has been to determine the inorganic chemical substances in average and representative well waters in many localities from the three sources, the alluvium, the drift, and the stratified rock. Springs of large flows from known formations have also received attention. Wells supplying towns or important industrial establishments have been investigated in preference to those supplying only a single home or farm. Little attention has been given to shallow wells reaching only a short distance into the clay and supplied from it by seepage, or to wells on river banks which evidently obtain their water from the rivers by percolation through a few feet of sand or clay.

The small funds for the work have made it necessary to avoid duplication. One or two wells of about the same depth and casing in a locality have been deemed sufficient to indicate the quality at that place, unless the wells were very deep and reached the extensive aquifers. Wells of the latter type are likely to be of more importance, and as a matter of fact their casings are likely to be of very different lengths and are frequently defective. It was, therefore, considered desirable to secure analyses of several such wells, even if close together, in order to eliminate the accidental to some degree and to draw more nearly accurate conclusions as to what quality of water the main sources of supply might be expected to furnish at that point.

ACKNOWLEDGMENTS.

This report contains about 400 analyses of well waters. Of this number nearly one-half have been made by the writer with some assistance in the chemical laboratory of Grinnell College. About 45 analyses have been taken from Norton.[1] Most of them were made by Prof. J. B. Weems, at that time of the Iowa State College at Ames. The remainder were obtained through the kindness of the chemists of the Iowa railroads, whose courtesy and fine spirit of cooperation it would be difficult to overstate. All who were written to and had such data as were requested sent all that were asked for and more. Hundreds of pen copies of analyses and blue-print sheets of analyses were sent in. The aid given by these men has been invaluable.

The greatest number of analyses was sent by Mr. George M. Davidson, engineer of tests of the Chicago & North Western Railway. He has also contributed a very full statement of the plants and processes used by his road in softening the waters along its lines for use in its engines.

Other who have shown the same generous and obliging spirit are Mr. W. D. Wheeler, of the Minneapolis & St. Louis Railroad; Mr. W. H. Chadburn, of the Chicago Great Western Railroad; Mr. M. H. Wickhorst, of the Chicago, Burlington & Quincy Railroad; Mr. George N. Prentiss, of the Chicago, Milwaukee & St. Paul Railway; and Mr. F. O. Bunnell, of the Chicago, Rock Island & Pacific Railway.

[1]Rept. Iowa Geol. Survey, vol. 6, 1896, pp. 353-407.

CHAPTER I.

TOPOGRAPHY AND CLIMATE.

BY HOWARD E. SIMPSON.

TOPOGRAPHY

RELIEF.

Iowa has but one primary physiographic form—the prairie plain. Taken as a whole it is the most typical prairie state of the Union. Here waving grasses once covered the rolling uplands and deciduous trees bordered the dark and slowly meandering streams. Now the deep, rich soils, moistened by ample and well distributed rainfall, offer rich return for agriculture, and artificial groves dot the landscape in every direction.

The relief is slight. The general surface elevation varies from 494 feet above sea level at Keokuk in the extreme southeast corner to 1.551 feet at Ocheyedan in Osceola county near the northwest corner, a range of slightly more than 1,000 feet. The total range in altitude between the low water of Mississippi river where it leaves the state at Keokuk and the highest mound on the great divide in Osceola county is not exactly known, but it does not exceed 1,200 feet, a slight relief for an area of 55,475 square miles.

Originally this plain was an old sea floor. The alternating layers of sands, muds, and lime deposits of which it consisted were slowly cemented and consolidated into sandstones and limestones and raised by gentle uplift into the great interior plain which slopes southward from the old lands of Canada and the Lake Superior region. Time did not materially disturb the rock layers of this ancient coastal plain except to bevel off their surface and they still dip away slightly to the southwest, with scarcely a fold or fault to break the unity. The surface variations were largely the result of long-continued erosion by weather and running water, greatly modified and almost obliterated over the larger portion of the state by glacial ice.

DRAINAGE.

Though lying entirely within the Mississippi basin, the rivers of the state, when viewed as a whole, are readily separable into two distinct systems, one of which drains to the Mississippi and the other to the Missouri. The divide between these two systems enters the state a few miles east of Spirit lake, passes southward through the eastern parts of Dickinson and Clay counties, thence through Buena Vista, Sac, Carroll, Guthrie, and Adair counties. Thus far it is a broad, flat, and inconspicuous ridge. The direct extension of this ridge, somewhat better defined than before, continues southward through Union, Ringgold and Decatur counties to the Missouri state line. The divide proper, however, turns eastward through Clarke, Lucas and Monroe counties, and thence goes southward through Appanoose county around the headwaters of Grand and Chariton rivers, which turn southwestward after crossing the state line and flow into Missouri river. The rivers of the Mississippi system have a southeastern trend, those of the Missouri system a southwestern trend consequent upon the original slope of the plain. The direction of the minor streams generally does not depend in any way on the character or structure of the underlying rock.

SUBDIVISIONS.

Though Iowa may not be divided into physiographic provinces on the basis of primary land forms, the work of the continental ice sheets in smoothing down the hills, filling up the valleys, and spreading a leveling mantle of drift over wide areas, has resulted in such marked modification of the preglacial topography that the state may be readily divided into the driftless area and the drift area:

DRIFTLESS AREA.

All of Iowa, except a narrow strip lying along Mississippi river in the northeast corner of the state and including Allamakee county and the northeastern portions of Winneshiek, Clayton, Dubuque, and Jackson counties has been overridden by glacial ice. The topography of this strip is in sharp contrast with that of the drift-covered area and must fairly represent the topography of the entire state before the great ice invasion. Weather and running water have had continuous and undisturbed action on nearly horizontal rocks of varying hardness for a long period of time, and the surface has reached the stage of mature dissection.

RELIEF.

Chief among the many interesting topographic features of the driftless area is the valley of the Mississippi. The Mississippi flows from the north through a remarkably steep-sided, rock-walled valley 400 to 500 feet deep and one to three miles wide, swinging south in great and gentle curves such as could be carved only by an earlier stream of far greater volume. The present Mississippi clearly misfits its valley, flowing through a braided network of shifting channels and leaving in its changes numerous ponds, lakes, and bayous on the broad plain which now forms its valley floor. That the valley has been extensively filled is evident from well borings, which reveal great thicknesses of sand, clay and gravel; at McGregor, for instance, 187 feet of sediment, evidently of glacial origin, is found above the ancient rock channel. The larger tributaries flow in rock-walled, flat-bottomed valleys 100 to 300 feet beneath abrupt bluffs on either side and 500 to 600 feet beneath the crests of rounded dividing ridges. Near their headwaters they flow through steep-sided rocky gorges, and their tributaries have sharply carved and thoroughly drained the uplands. Farther down the walls retreat, the uplands break into rugged ridges, rounded hills, and flat-topped mounds. Here and there, as between Turkey and Mississippi rivers, they terminate in the sharp points crowned with picturesque pinnacles, towers, and long mural escarpments that result from the presence of strong cliff-forming rocks underlain by weaker slope makers.

The main valleys have been cut considerably deeper than their present floors and are aggraded with alluvium, probably Pleistocene in age. Thus the wells at New Albin strike rock at from 130 to 140 feet from the surface, or more than 100 feet below the present river levels. Moreover, old terraces, remnants of ancient flood plains, standing as high as 60 feet above the rivers, mark the height of the streams of the region when they ceased aggrading their rock-cut valleys and resumed the task of degradation.

SOILS.

The soil of the area is chiefly residual, resulting from the decay of the country rocks in place. The upland, however, is broadly mantled by loess, a fine, porous clay. Many of the steep slopes characteristic of the region are nearly bare, the loess cover being generally absent. The larger valley floors are commonly filled with water-bearing sands and gravels, overlain by rich alluvium.

DRAINAGE.

The drainage system of the driftless area is completely developed except for the lakes and other undrained areas on the flood plains. Underground drainage is not uncommon in the area underlain by limestones, as is shown by sink holes, limestone caverns in the uplands, and numerous large springs which rise in the valleys. The topography of the driftless area has a very marked influence on the underground water conditions. In the deep dissection of the country the many water-bearing beds, such as limestone and sandstone, are cut through in many places by the stream valleys, and the water is permitted to escape as seepage and as springs from numerous joints and fissures or over shale horizons.

The slopes are so numerous and steep that water can not linger on the uplands in pools or ponds, but is shed rapidly into the streams, affording little opportunity for either evaporation or absorption and giving rise to occasional floods, which cause serious damage to towns like McGregor and Decorah, which are situated in the valleys.

The residual soil is tenacious and relatively impervious, and so absorbs little water. The loess is porous but comparatively thin. The broad, flat uplands away from the valleys are the best retainers of moisture. In them the ground-water level stands high, and shallow wells may be had in many places, though the supply is scanty, for seepage is slow. The ground-water level, as a rule, however, stands low, owing to natural drainage through deep dissection. Rock wells are most common and depths of from 300 feet to 600 feet are not unusual. In the valleys the ground-water level is but slightly below the surface, and the gravels and sands in the filled valleys carry a strong underflow, yielding abundant water at slight depths.

DRIFT AREA.

GENERAL CHARACTER.

With the exception of the driftless area above described, every portion of the state of Iowa was occupied by an ice sheet at least once during the glacial epoch. The general effect of the ice work was to wear away the more prominent topographic prominences, to fill the valleys, and to spread rock waste over the area. Portions of the state were several times invaded by ice, which left the sheets of till, varying in smoothness and thickness, that combine to form the present mantle of drift—a mantle averaging in thickness from 100 to 200 feet, with a probable maximum of 600 feet in Louisa county.

The topography of this region is young as compared with that of the driftless area, and is generally independent of the geologic structure of the underlying rocks. Only along the margins bordering the driftless area and in the valleys of the larger streams is it influenced by the preglacial topography. The topographic features are chiefly due either to the manner in which the ice laid down its load of waste or to the subsequent action of the agents of erosion.

On the whole, the surface left on the retreat of the glacial ice was a gently undulating plain. Only near the margins of the drift sheets or at places where long pauses were made in the retreat of the ice front were marked irregularities produced.

Here belts of hills with alternating depressions were formed by the irregular heaping up of the drift material, producing terminal or recessional moraines having characteristic knob and kettle topography. The material is chiefly till, a mixture of clay, sand, pebbles and bowlders of all kinds, deposited directly by the ice. Associated with this are beds of sand and gravel left by streams of running water and fine clays deposited in quiet waters. Overlying the drift sheets of the earlier ice invasions over more than half the state is a fine, porous clay of peculiar vertical cleavage called loess. This formation is of eolian or aqueous origin and can be readily distinguished from the underlying drift by its lack of pebbles and bowlders. It tended to smooth over the slight inequalities of the drift sheets on which it was deposited.

DRIFT SHEETS.

At least five different ice invasions, each of which deposited a sheet of drift, entered Iowa from slightly different directions and at widely separated periods of time during the glacial epoch. The drift of the first invasion, known as the Nebraskan (pre-Kansan) was everywhere overridden by later ice sheets and is not known to influence the topography of the state. The deposits of the remaining four invasions, the Kansan, Illinoian, Iowan and Wisconsin are represented on the surface by areas of drift differing only slightly in composition but very greatly in age and topographic form.

KANSAN DRIFT.

The oldest drift sheet appearing on the surface in Iowa is the Kansan, which heavily mantles the entire state with the exception of the driftless area already described and is exposed in the southern and western portions over an area equal to half the area of the state. A line connecting Fort Madison, Iowa City, Des Moines, Carroll and Sibley roughly separates the exposed Kansan area from that to the north and east, which is covered by younger drift sheets.

The evidence offered by unaltered remnants of the old Kansan drift leads to the inference that its surface must have been very gently undulating and have been characterized by the absence of moraines, drumlins, kames, and other hills due to accumulation. The relief of today has therefore been developed by the action of weather and running water through long periods of time. So long have these agents of erosion been at work on the Kansan area that they have in most places drained it and reduced it to a high degree of maturity characterized by a heavily rolling topography.

The drainage is so complete that lakes, ponds and other bodies of standing water are practically unknown except on the flood plains of large streams. The slopes are so steep and the run-off so rapid that little opportunity for absorption or for evaporation is given as compared with the areas of younger drift. On the other hand, the loess cover is so porous as to absorb a slow rainfall very rapidly. The ground water is relatively low, especially on the higher region about the Mississippi-Missouri divide. It is higher, however, than in the maturely dissected region of the driftless area, where slopes are very steep and soils tenacious.

Not all the uplands are so thoroughly dissected. Away from the larger rivers broad flat-topped divides retain many of the surface features of the original drift plain. Long, low swells alternate with shallow swales, through which sharp stream channels have been excavated by storm waters. A few damp sloughs and small patches of marsh grass in gentle depressions indicate that here at least youth lingers in the midst of maturity. In such an upland much of the storm rainfall is absorbed; ground-water level is found close to the surface in the swales; and shallow wells are common, even on the low swells where the houses are located.

Nearer the rivers little of the plain remains and the country is sharply broken into hills and valleys. The slopes, though not so steep as in the driftless area, show frequent outcrops of bedrock, from which springs flow in places and seepage is common. The larger streams occupy broad flat bottomed valleys and meander over well developed flood plains. So long have they worked that many of them have discovered preglacial channels in which they are now flowing. In the valleys the ground-water table coincides with the surface of the stream and rises in general toward the valley sides. Shallow dug wells reach water a few feet down; where gravels and sands have been deposited in the valley the underflow is strong and easily obtained by means of driven wells.

Owing to the steeper slope of the plain in the southwestern portion of the state, west of the Mississippi-Missouri divide, and the short distance of the headwaters from the master stream, a maturity has been attained beyond that of any other drift covered portion of the state. The rivers flow through deep, broad, nearly parallel valleys, the floors of which are underlain by gravel, sand and clay. Most striking of the valleys, perhaps, are those of Nishnabotna and Nodaway rivers. The valley floors of these range from one to four miles in width and are so terraced that only a narrow belt is exposed to frequent flood water. Throughout the valleys shallow wells furnish an abundance of good water from the sand and gravel layers of the alluvium.

Missouri river, on the western border of Iowa, lies within the area of Kansan drift, and meanders through a postglacial valley partly filled with yellow loess. Its broad flood plain, constantly shifting channel, muddy waters, and ever present snags, are among its most striking characteristics.

ILLINOIAN DRIFT.

In the southeast corner of the state a small area of younger drift overlies the Kansan, extending along Mississippi river from Princeton to Fort Madison in an irregular belt five to twenty miles in width. The depositing ice sheet came from the northeast and the drift is known as the Illinoian. The surface of the whole is thickly mantled with loess.

Several important rivers, among which are the Cedar, Iowa and Skunk, have had a marked influence on the topography in the vicinity, excavating deep, wide valleys in the soft drift.

The greater part of the area retains the characteristic features of a young drift plain. Few sloughs remain and the storm waters have washed out well-marked drainage channels, but broad tabular areas of the original plain still persist, forming large, level, floor like divides. The Mississippi here occupies a narrow channel whose youth is indicated by rock-cut portions at Le Claire, Davenport and Keokuk.

At its western margin the Illinoian drift sheet thickens into a low morainal ridge, beyond which a broad flat channel, roughly paralleling the Mississippi from Bellevue to Fort Madison, marks the temporary channel occupied by that river while diverted by the Illinoian ice. In "The Forks" between Cedar and Iowa rivers in Louisa and Muscatine counties lies a level sandy plain, the bed of an extinct glacial lake, whose waters were held between bluffs bordering Iowa river on the west and the ice front on the east. The diverted Mississippi, flowing down from the northeast, was here blocked and ponded until it rose sufficiently to flow away southward over the bluffs through the channel mentioned above.

The loess cover of the Illinoian drift readily absorbs water and the general ground-water level stands high except in the broken areas near the larger rivers and at the margins of the drift. In such places the conditions resemble those in the Kansan area.

IOWAN DRIFT.

Over the greater part of the northeast quarter of the state lies the drift left by the Iowan ice sheet. Its borders on the south and east are remarkably sinuous owing to the projection of many long, narrow tongues. It is overlain on the west by the younger Wisconsin drift, the margin of which lies near Clear Lake and Eldora. Its southern margin passes near Grinnell, Belle Plaine and Iowa City. On the east it is separated from the driftless area by a narrow belt of Kansan drift.

The topography of the region is characteristic of a youthful drift plain. The irregularities left in the drift by the departing ice sheet still remain. The loess, which so fully mantles the older drift sheets in the southern part of the state, is conspicuous by its absence, being found only in irregular patches near the margin. The surface is gently undulating. Low flat swells alternate with swales, on whose broad floors "sloughs," marshy remnants of glacial lakes, give rise to small creeks which follow a sluggish, winding course toward the master streams. In the northeast portion bowlders strew the surface, especially in sags and swales. Near the southern margin of the Iowan area the even surface rises into low hills with parallel axes, apparently drumloid in character, but capped with loess. To these hills the name paha has been given. Along the southwestern margin in Tama and Benton counties they become more knobby and much resemble a terminal moraine.

The river valleys are not well developed, as in the area of the Kansan drift, but flow in narrow channels between steep banks of drift and alluvium except where they have found preglacial channels held open during ice invasion.

Natural drainage is not complete in the Iowan drift area, but the process is being rapidly hastened by artificial means. In no other part of the state can man so easily aid nature in this respect. The young stream courses are well marked and, when once the sod in their bottoms has been broken by the plow, they deepen rapidly and form the outlets for extensive systems of tile drainage. The excess of water which would otherwise form ponds and sloughs in the low flat areas is thus readily drained off, yet so slightly is the ground-water level lowered beneath the surface that the normal moisture is retained during dry seasons, a most favorable condition for agriculture.

Thruoghout the Iowan area the ground-water level stands high. The lack of the porous loess cover probably tends to increase evaporation and run-off, but owing to the flatness of the surface the run-off is slow. Most wells find water within a few feet of the surface, but owing to the imperviousness of the drift many fail to obtain a large supply until they penetrate the bed-rock.

WISCONSIN DRIFT.

The youngest of all the drift sheets in Iowa, that deposited during the Wisconsin ice invasion, lies in a broad lobe extending from the north boundary of the state to the city of Des Moines. The western margin lies near Sibley, Storm Lake and Panora, and the eastern margin near Clear Lake, Iowa Falls and State Center.

The area presents all the characteristics of early youth. It is a level, undissected drift plain in which the drainage remains strikingly incomplete, the topography being practically as the ice sheet left it. Low rounded swells separate shallow basins, in which lie numerous sloughs, lakes, ponds and peat bogs. The smaller streams wander in narrow, crooked valleys and in many places end in undrained basins. The rivers are simple consequent streams; some occupy shallow channels on the surface of the plain and others have cut deep trenches in the drift, but all lack well-developed systems of tributaries.

A feature of this drift area is the accumulation of well-marked terminal moraines on the eastern and western margins, together with several recessional moraines within the area. On the eastern margin a distinct belt of knobs 50 to 100 feet in height enters the state along the north boundary of Winnebago county and passes southward through Hancock, Cerro Gordo, Franklin and Hardin counties, dying out in the western part of Marshall county. On the west side another belt, partly terminal and partly recessional, enters Dickinson county and curves southward through Clay, Palo Alto, Buena Vista, Sac, Carroll and Greene counties and dies out in the northeast corner of Guthrie county. Well-marked recessional moraines are found in northern Boone and adjacent counties and in Webster county.

The Wisconsin drift area is the lake region of Iowa. A few ponds and sloughs occur in the Iowan drift area, and lagoons, cut-offs, and bayous are found on the flood plains of all the larger rivers of the driftless area and of the Kansan drift area, but the only lakes of importance in the state are found in the Wisconsin area and are of glacial origin. They lie chiefly within the heavy morainal belt already described and occupy irregular depressions between the kames. Chief among them are Spirit, East and West Okoboji, Storm, Wall and Clear lakes. The last named furnishes the water supply for the town of Clear Lake, and several are valuable sources of ice.

The problem of adequate drainage is more difficult in the Wisconsin area than anywhere else in Iowa. The lakes, ponds and sloughs all indicate a high ground-water level. The absence of the loess leaves the drift without a porous cover and the tenacious quality of the bowlder clay prevents the entrance of much water into the ground. Wells in swales therefore find abundant water, but on the higher portions they must be driven deep, frequently into rock, to get a plentiful supply. The surface waters are so abundant, however, that fewer stock wells are necessary than in other areas.

SUMMARY.

The level character of the prairie plain is such as to favor the ready absorption of rainfall by the soils and to cause the ground water to stand near enough to the surface of the drift or the country rock to be within easy reach of comparatively shallow wells. The gently rolling character of the topography insures good drainage, thus preventing stagnation of water on the surface, and lowers the ground-water level far enough to permit purification of the downward percolating waters by filtration before they join the great underground system. The topographic conditions, in connection with drift soils such as are found throughout nearly all of the state of Iowa, insure an abundant and wholesome supply of underground waters at depths which permit most of the inhabitants outside of the large cities to be supplied at very slight cost.

CLIMATE

GENERAL CONDITIONS.[1]

The climatic conditions of the state of Iowa are, on the whole, favorable to a good and constant supply of underground water. Most important of these conditions are precipitation and temperature, both of which, though liable to marked variations from the normal, are shown, by the abundant annual rewards of agriculture, to be favorable to the storage and conservation of the moisture in the soils and country rock. Nothing approaching a failure of crops either by drowning or drought has been experienced in the history of Iowa—a history which now spans more than three-quarters of a century.

Climatic observations within the present boundaries of Iowa were officially taken by the medical officers of the United States

[1]Detailed information regarding climatological conditions in Iowa may be found in the following reports: Sage, J. R., Climate and Crops of Iowa: Ann. Rept. Iowa Weather and Crop Service for 1902, appendix. Henry, A. J., Climatology of the United States, U. S. Weather Bureau, Bull. No. Q, 1906, pp. 626-658.

military posts as early as 1820, and widely scattered, though systematic, records were kept with standard instruments under the direction of the War Department and the Smithsonian Institution until 1870, when the Weather Bureau was established. Since 1890 the state government has cooperated with the Weather Bureau through the Iowa Weather and Crop Service.

There exists, therefore, a series of records covering a period of nearly ninety years, during all of which time much attention has been given to both temperature and rainfall. Though the early records are few and incomplete they are of value in indicating the constancy of the Iowa climate and the error of many who have not carefully studied the conditions in believing that marked changes have taken place. The observed facts make it highly improbable that any important change in the average precipitation of either rain or snow has taken place since the settlement of the region by civilized people.

TEMPERATURE.

The mean annual temperature is 47.5° F. The variation from this figure scarcely ever exceeds 2°; but owing to the location of the state in the interior of the continent, exposed alike to cold waves from the northwest and warm waves from the south, the average annual range of temperature amounts to 136°. The highest temperature recorded is 113° and the lowest is —43°, giving the remarkable range of 156° between the highest and lowest observed temperatures. The mean annual temperature decreases gradually and uniformly from Keokuk, the lowest and most southerly point in the state, to the higher parts of the north-central region.

The table below gives the monthly, seasonal, and annual mean temperatures as recorded at six climatologic stations of the United States Weather Bureau in Iowa and one at Omaha, Nebraska. The distribution of these seven stations is such as to represent fairly well all portions of the state. To these are added for comparison the corresponding mean temperature for the state as a whole.

Monthly, seasonal, and annual mean temperatures (°F.) in Iowa and at Omaha, Nebraska.

Station	January	February	March	April	May	June	July	August	September	October	November	December	Winter	Spring	Summer	Autumn	Annual
Charles City	16	14	31	48	60	68	73	71	63	50	32	19	16	46	71	48	45
Dubuque	18	21	33	49	61	70	75	72	64	52	36	25	21	48	72	51	48
Sioux City	20	19	32	50	60	70	74	72	64	52	34	25	21	47	72	50	48
Des Moines	20	23	35	51	61	70	75	73	65	53	37	26	23	49	73	52	49
Davenport	21	24	35	50	61	71	75	73	65	53	38	27	24	49	73	52	50
Omaha, Nebraska	21	25	36	52	62	72	76	74	66	54	38	27	24	50	74	53	50
Keokuk	24	28	38	52	63	72	77	75	67	55	39	30	27	51	75	54	52
Iowa	19.3	19.2	34.0	48.5	60.1	68.8	73.4	71.8	63.7	51.9	35.9	23.6	20.7	47.5	71.3	50.5	47.5

The first killing frosts of autumn occur about October 5 and the last of spring about April 25, the time varying about two weeks between the northern and southern portions. This gives a period of about six months during which frost is liable to occur. The streams are closed by ice for approximately three months and the surface of the ground is sufficiently frozen to prevent ready absorption of rainfall for about four and one-half months.

The relations of temperature to ground water are very complex. They include (1) the immediate and direct relations that govern the amount, rate, and form of the precipitation; (2) those that determine the proportionate parts of the rainfall that evaporate, run off, or are absorbed, as affected by the character of the surface and by its freezing, baking, etc.; and (3) those that govern the direct movements of ground water. The last item is often overlooked, but its importance may be suggested by the fact, determined by experiment, that water at 100° F. percolates twice as rapidly through sand as it does at 50°; both absorption and flow, therefore, vary greatly with the temperature.

PRECIPITATION.

CONTROLLING CONDITIONS.

The moisture which falls in the form of rain or snow over Iowa comes chiefly from the Gulf of Mexico, being drawn in with the southerly winds toward the rotating areas of low pressure (or cyclones, as they are technically called), which move eastward across the continent with the prevailing westerly winds. These cyclonic storms are great in area, moderate in force, and beneficial in effect. They should not be confused with the violent rotating storms properly called tornadoes, which occasionally occur in the middle and eastern parts of the United States, making a very narrow track and extending over a small area. The rainfall is directly cyclonic in winter and indirectly cyclonic in summer, coming chiefly from thunder storms in the southeastern quadrant of the low-pressure areas. Many of the thunder storms, which average about 37 annually for each station in the state, are, however, of the conventional type and are therefore local.

GEOGRAPHIC DISTRIBUTION.

The Iowa Weather and Crop Service has divided the state into three sections, northern, central, and southern, each consisting of three tiers of counties, extending across the state from east to west. The average annual precipitation of the northern section is 29.9 inches, of the central section 31.5 inches, and of the southern section 33.6 inches. Each section has been subdivided into three districts more or less closely approximating rectangles and containing from 7 to 15 counties each. The names of these districts together with their average annual precipitation are: northeast, 32.25 inches; north-central, 29.40 inches; northwest, 28.16 inches; east-central, 32.61 inches; central, 31.66 inches; west-central, 29.36 inches; southeast, 33.65 inches; south-central, 32.53 inches; southwest, 32.60 inches.

The highest average precipitation is found in the southeast district and the lowest in the northwest. The southeast district has an annual average of 5.49 inches more than the northwest district, 1.40 inches more than the northeast district, and 1.05 inches more than the southwest district. From these figures it is readily seen that there is a regularly decreasing gradient from east to west and a slightly steeper one from south to north, the steepest gradient being from southeast to northwest.

The highest annual average at any of the United States Weather Bureau stations is 35.2 at Keokuk in the extreme southeast corner of the state, and the lowest average is 25.8 at Sioux City, near the northwest corner; this confirms the relations above stated and gives a range of 9.5 inches in the mean annual precipitation as recorded at the different Weather Bureau stations within the state.

Grouped in north-south belts, the eastern or Mississippi river belt has an average annual precipitation of 32.50 inches; the middle belt of 31.51 inches; and the western or Missouri river belt of 30.04 inches.

Thus, the variations in the geographic distribution of the precipitation of Iowa are slight, consisting chiefly of a normal decrease northward and a decrease northward and westward with increase in distance from and elevation above the chief source of the moisture, the Gulf of Mexico, and with increase in distance from the usual paths of the cyclones.

SEASONAL DISTRIBUTION.

To give a perfect idea of the relation of rainfall to underground waters the records should show not only the amount, but the rate of the fall, the cloudiness, the direction and velocity of the wind, and the condition of the ground surface at the time. Precipitation falling on a moderately dry surface is absorbed more rapidly than that falling on hard-baked ground, and still more rapidly than that falling on a frozen surface, which is scarcely absorbed at all unless it falls as snow. Winter precipitation is therefore of little value as compared with summer precipitation.

In spite of the location in the interior and of the great distance from the source of supply the constancy of the prevailing westerly winds and the frequent recurrence of the cyclones produces a seasonal constant of rainfall which, coupled with the peculiar character of the glacial soil, makes the upper Mississippi valley a well-watered region. As the supply of ground water, especially that near the surface, depends on the rainfall, the amount of precipitation and its geographic and seasonal distribution is important. The average annual precipitation as shown by official record is about 31.5 inches. Its seasonal distribution is fairly well shown in the table below, which gives the mean monthly, seasonal and annual precipitation for the several Weather Bureau stations and for Iowa as a whole.

Monthly, seasonal, and annual mean precipitation (inches) in Iowa and at Omaha, Nebraska.

Station	January	February	March	April	May	June	July	August	September	October	November	December	Winter	Spring	Summer	Fall	Annual
Charles City	0.9	1.0	1.7	3.0	4.3	4.[illegible]	3.[illegible]	3.[illegible]	3.[illegible]	2.[illegible]	1.4	1.1	3.0	9.0	11.2	**6.6**	**29.8**
Dubuque	1.5	1.4	2.2	3.0	4.3	4.7	4.7	2.9	4.2	2.6	1.9	1.6	4.5	9.5	12.3	8.7	35.0
Sioux City	.5	.6	1.2	2.8	4.1	4.0	3.5	3.1	2.4	1.7	.8	.8	1.9	8.1	10.6	4.9	25.5
Des Moines	1.2	1.1	1.6	2.9	4.8	5.0	3.7	3.5	3.0	2.8	1.5	1.3	3.6	9.3	12.2	7.3	32.4
Davenport	1.6	1.6	2.2	2.7	4.4	4.1	3.7	3.6	3.2	2.4	1.8	1.6	4.8	9.3	11.4	7.4	32.9
Omaha, Nebraska	.6	.7	1.4	3.0	4.4	5.2	4.6	3.5	2.9	2.5	1.0	1.0	2.3	8.8	13.3	6.4	30.8
Keokuk	1.8	1.6	2.4	3.2	4.2	4.4	4.2	3.0	3.8	2.7	2.0	1.8	5.4	9.8	11.6	8.5	35.1
Iowa	1.05	1.06	1.92	2.83	4.50	4.52	4.44	3.99	3.41	2.35	1.39	1.19	3.30	9.25	12.95	7.15	32.65

Iowa has fairly well-defined wet and dry seasons, due to the migration of the wind system with the sun. The bulk of the rainfall occurs during the spring and summer months and little of it during the winter months, the approximate percentages being, winter 10 per cent, spring 28 per cent, summer 39 per cent, and autumn 23 per cent. Only a small proportion falls during the period in which the ground is frozen and absorption prevented, and a very large proportion, probably 80 per cent, falls in late spring and summer when absorption is greatest. This natural advantage is greatly increased by the fact that the heaviest rainfall occurs during the seasons for the preparation and the cultivation of the soil, thus very greatly increasing the absorption. This relative increase of precipitation of spring and summer over that of winter becomes more marked as the total rainfall decreases from the Mississippi westward. The summer precipitation at Keokuk is 11.6 inches and that at Sioux City is 10.6, a difference of but 1 inch; whereas the winter precipitation at Keokuk is 5.4 inches and that at Sioux City is 1.9 inches, a difference of 3.5 inches, thus compensating to a large degree for the differences in total rainfall.

A marked effect of the diminution of precipitation during the winter months is noted in the slightness of the snowfall compared with that of the more eastern states. Though snow falls in all parts of the state, the annual average fall for 29 years is but 29.2 inches, less than one-tenth of the precipitation. The effect of geographic differences in precipitation on the underground-water supply is thus very slight.

VARIATIONS.

The table below shows that the precipitation for the entire state is subject to marked variations from year to year. Since 1890 the lowest average for the whole state for a single year was 21.9 inches in 1894 and the highest 43.8 inches in 1902. Between these extremes there has been marked variability, but the tendency to one extreme is frequently followed by a tendency to the other, as illustrated in the dry year of 1901 and the wet year of 1902. The general average has been steadily maintained through all the long period covered by records.

Yearly Variations of Rainfall in Iowa.

[Inches]

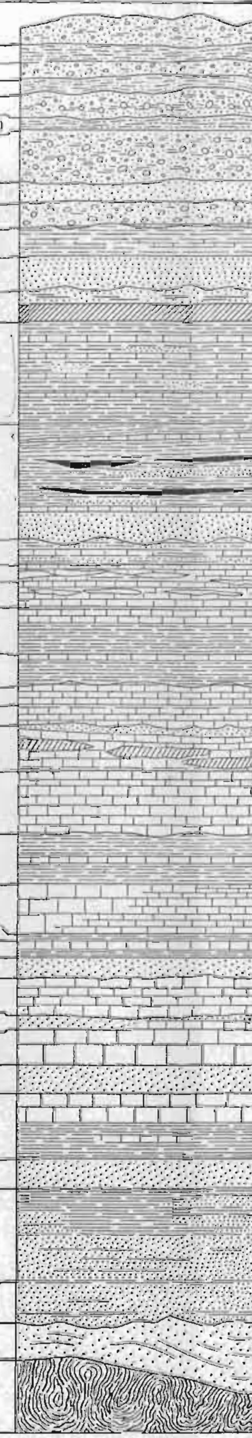
Year	Average	Variation from normal	Year	Average	Variation from normal
1890	31.28	—0.24	1902	43.82	12.30
1891	32.90	1.38	1903	35.39	3.87
1892	36.58	5.06	1904	28.51	— 3.01
1893	27.59	—3.93	1905	36.56	5.04
1894	21.94	—9.58	1906	31.60	.08
1895	26.77	—4.75	1907	31.61	.09
1896	37.23	5.71	1908	35.26	2.61
1897	26.97	—4.55	1909	40.01	7.36
1898	31.34	— .18	1910	20.03	—12.62
1899	28.68	—2.84	1911	31.57	— 1.28
1900	34.15	2.63			
1901	24.41	— 7.11	Average	31.51	

Deficiency of summer rainfall sometimes produces droughts, the effect of which is marked on the streams, springs, and shallow drift wells, producing scarcity of water for stock and for domestic purposes. Heavy drains are made for stock on the deeper rock wells when streams are low, and as these rock wells are of small bore they are sometimes temporarily exhausted. The texture of the soil and other physical conditions, such as its condition at the beginning of the dry period, determine its ability to store water under the least loss by evaporation. Rather severe general midsummer droughts occur at irregular intervals once or twice in a decade. During all such droughts, however, many small areas have had practically normal precipitation, and the amount has generally been ample in most parts of the state.

The most severe drought on record is that of 1894-95, which may be ascribed to slight precipitation and high temperatures for two successive seasons. The precipitation for July, 1894, was only 0.63 inch, about 15 per cent of normal, and for August was 1.58, about 44 per cent of normal. The departure from the annual precipitation during the year was—9.5 inches. The extreme in the other direction in recent years occurred in 1902, when the precipitation reached 43.82 inches for the year, 12.30 inches above the normal.

SUMMARY.

The information for a satisfactory discussion of evaporation, humidity, wind velocity, and other minor factors in the meteorologic control of ground-water supply is insufficient, but enough data are available in regard to the two chief controlling factors, temperature and rainfall, to show that Iowa, though possessing the variable characteristics of a continental climate, also possesses the requisite meteorologic conditions for a moderately abundant supply of underground water.

ERA	SYSTEM	SERIES	GROUP	FORMATION	COLUMNAR SECTION	CHARACTER OF STRATA
Cenozoic	Quaternary with patches of Tertiary at base	Pleistocene		Wisconsin drift		Stony clay, kame, and outwash gravels
				Loess, soil bed, etc. (Peorian interglacial stage)		Soil bed, loess, etc.
				Iowan drift		Stony clay
				Soil, etc. (Sangamon interglacial stage)		Soil and vegetal accumulations
				Illinoian drift		Stony clay
				Buchanan gravel; soil,etc. (Yarmouth interglacial stage)		Soil, gravel, sand, and vegetal accumulations
				Kansan drift		Stony clay and outwash gravels
				Gravel, sand, peat, etc. (Aftonian interglacial stage)		Gravel and sand, soil, peat, and forest beds
				Sub-Aftonian drift		Stony clay
						In places stiff, plastic, and impervious clays of Tertiary age are present at the base of the Quaternary
Meso-zoic	Cretaceous	Upper Cretaceous	Colorado			Shales, limestones, chalk
				Dakota sandstone		Sandstones, friable
Paleozoic	Carboniferous	Permian (?)				Red shales and sandstones
						Gypsum
		Pennsylvanian	Missouri			Shales, limestones, some sandstones, and coal
			Des Moines			Shales, some sandstones and limestones, and coal
		Mississippian		"St. Louis limestone"[b]		Limestones, sandstones, shales
			Osage[a]	Keokuk limestone Burlington limestone		Limestones, cherts, geodiferous shales
			Kinderhook			Shales, magnesian and oolitic limestones, and sandstones
	Devonian	Upper Devonian		Lime Creek shale, Sweetland Creek shale, and State quarry limestone		Shales and limestone
		Middle Devonian		Cedar Valley limestone		Limestones
				Wapsipinicon limestone		Limestones and some shales
	Silurian			Salina (?) formation		Dolomites and limestones, gypsum and anhydrite marls, sandstones
				Niagara dolomite		Dolomites
	Ordovician			Maquoketa shale		Shales with some limestones
				Galena dolomite		Dolomites and limestones
				Decorah shale		Green shale
				Platteville limestone		Limestones and shales
				St. Peter sandstone		Sandstone, white rounded grains
			Prairie du Chien	Shakopee dolomite		Dolomite, often arenaceous
				New Richmond sandstone		Sandstone
				Oneota dolomite		Dolomite
	Cambrian			Jordan sandstone		Sandstone
				St. Lawrence formation		Dolomites, marls, shales
				Dresbach sandstone		Sandstone
				Undifferentiated Cambrian		Sandstones, marls, shales
Proterozoic	Algonkian (?)			Red clastic series		Red sandstones
	Algonkian	Huronian		Sioux quartzite		Quartzite
	Archean			Gneiss and schist		Gneiss and schist

[a] As used in this report includes at top the lower part of the Warsaw limestone

[b] Includes upper part of Warsaw limestone

GENERAL GEOLOGIC SECTION OF IOWA — BY W. H. NORTON

CHAPTER II.

GEOLOGY.

BY W. H. NORTON AND HOWARD E. SIMPSON.

GENERAL CONDITIONS

The rocks exposed in Iowa belong to four great divisions separated from each other by pronounced unconformities. (See Pl. I, in pocket.)

The oldest division belongs to the Algonkian system and is represented by the Sioux quartzite. This quartzite outcrops over only a small area in the northwest corner of the state but occurs more widely below other formations, and is also found at the surface over considerable areas in Minnesota and South Dakota.

The second division is represented by rocks of the Cambrian, Ordovician, Silurian, Devonian, Carboniferous and Permian systems, and includes a basal series of clastic beds that may be of Algonkian age. This great assemblage of sediments rests on an uneven floor composed of Sioux quartzite and older crystalline rocks. It consists of beds of sandstone, shale, and limestone, many times repeated in varying order. Where these beds come to the surface they have been carefully studied, and the order of their succession has been determined. (See Pl. II.) They are for the most part apparently conformable with one another, but important erosional unconformities occur at the base of the Devonian system and between the Mississippian, the Pennsylvanian, and the Permian. The oldest exposed rocks of this division are of Cambrian age and outcrop in the northeastern part of the state. The strata dip in general toward the southwest, and in this direction the younger formations become successively the surface rocks. The boundary lines between the formations, at the surface or immediately below the drift, follow in general the strike of the rocks, and, hence, are approximately parallel and cross the state with a northwest-southeast trend. (See Pl. I.) Where the principal unconformities occur, however, the boundaries depart from this parallel arrangement.

The third great rock division of Iowa is represented by Upper Cretaceous sandstones, shales, and limestones, which lap over the older formations, and cover much of the northwest and west-central parts of the state.

The fourth great division includes the drift sheets and associated subaerial, interglacial, and postglacial deposits of the Pleistocene series. These deposits were spread over nearly all of the state except the northeast corner, and in most localities they still cover the older rocks. The distribution of the different Pleistocene formations is shown in Plate III, in pocket.

The rock structure is shown in detail in the geologic sections, Plates V to XVIII, inclusive. The location of these sections is indicated in figure 1.

PRECAMBRIAN ROCKS

ARCHEAN SYSTEM.

Foliated rocks—schists and possibly gneisses—have been found in several deep wells in the northwestern part of Iowa. At Sioux City they were reached at a depth of 1,260 feet (135 feet below sea level), and continued to the bottom of the drill hole, which is 2,000 feet in depth. At Le Mars a rock called by Todd "a gneiss (?)," consisting of orthoclase, quartz, and muscovite, occurs at 215 feet above sea level, and crystalline foliated rocks, either gneisses or schists, continued for 500 feet to the bottom of the boring.

ALGONKIAN SYSTEM.

SIOUX QUARTZITE.

The Sioux quartzite (popularly but erroneously called "Sioux Falls granite") outcrops over a very small area in the northwest corner of the state. This familiar building stone of our

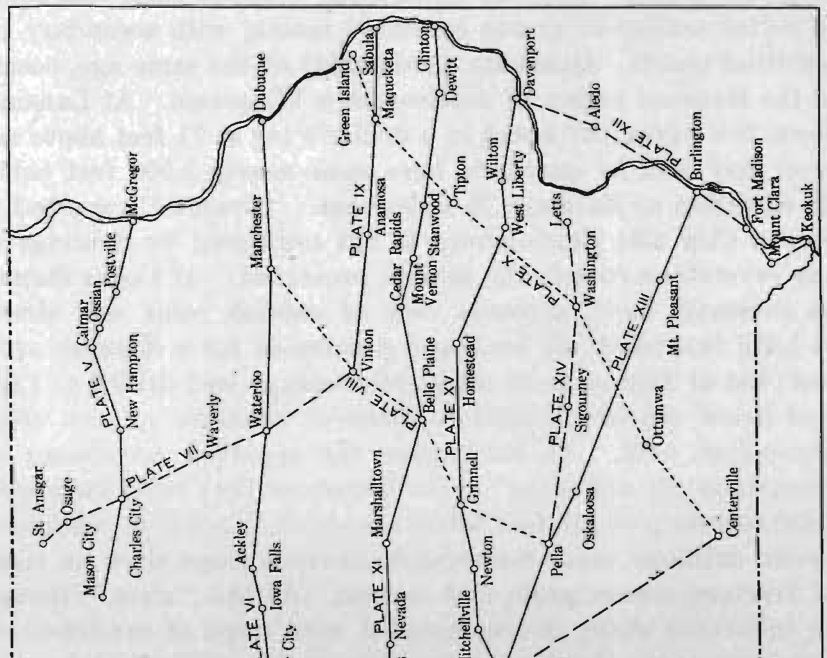


Figure 1.—Index map showing the location of geologic sections shown in Plates V-XVIII, inclusive.

large cities is an intensely hard, pink, vitreous rock, consisting of rolled sandstone grains cemented mainly with secondary interstitial quartz. Quartzite, presumably of the same age, occurs in the Baraboo region of southwestern Wisconsin. At Lansing, Iowa, the "granite" noted in a driller's log at 71 feet above sea level may well be quartzite, here sunk nearly 1,500 feet below its elevation at Baraboo, 75 miles east. "Granite" reported at Mason City and Emmetsburg is not confirmed by drillings of any crystalline rock in the sample preserved. At Cedar Rapids an intensely hard, siliceous rock of reddish color was struck at 1,417 feet below sea level and penetrated for a distance of 75 feet; but at Tipton, in an adjacent county, a well drilled to 1,886 feet below sea level failed to discover quartzite or any other crystalline rock. At Burlington the reported occurrence of "quartzite (?) and slate" at the bottom of the Crapo Park well, 2,430 feet deep (1,745 feet below sea level), is not fully confirmed by the drillings, since the reddish siliceous chips show no signs of fracture across grain and cement, and the "slate," though an indurated shale, is accompanied with chips of sandstone of Cambrian type. In the not far distant deep well at Aledo, Illinois, no crystalline rock was found, although a depth of 3,000 feet was attained.

ALGONKIAN (?) SYSTEM.

RED CLASTIC SERIES.

Certain deep wells of Iowa reach red sandstone beneath Cambrian terranes. Like the red sandstones of the deep wells of Minnesota, these red sandstones of Iowa seem to be dry, and they may be of Algonkian age. At Tipton the drill reached these red rocks at 1,435 feet below sea level, or about the level at which quartzite occurs at Cedar Rapids, and penetrated them for 431 feet to the bottom of the drill hole.

SANDSTONES WITH INTRUSIVE SHEETS.

The deep well at Hull, in northwestern Iowa, encountered, at 755 feet from the surface (678 feet above sea level), the first of six beds of quartz porphyry intercalated between saccharoidal sandstones, the entire series reaching to a depth of 1,228 feet from the surface (205 feet above sea level).

In the absence of any physical or lithologic characteristics determining the age of the sandstones, they have been regarded as probably of Algonkian age, on account of the known igneous intrusions of the same nature in the Keweenawan, the dikes of ancient lava in the Sioux quartzite, and the absence of volcanism in Paleozoic strata of the upper Mississippi valley.[1]

CAMBRIAN SYSTEM

OCCURRENCE AND SUBDIVISIONS.

The Cambrian rocks of Iowa were laid down upon an old sea floor which is now exposed far to the north in Minnesota and Wisconsin. They probably underlie the entire state, but rise to the surface only in the deep valleys of the extreme northeast corner. The younger formations overlie the older in the order of their deposition and become the country rock to the south and west in successive roughly parallel bands, each in turn dipping gradually to the southwest and passing underneath the next younger. The strata of the two oldest sedimentary systems represented, the Cambrian and Ordovician, follow one another in rapid succession and the narrow bands of their outcrop roughly parallel one another in intricate patterns.

The Cambrian, a system of massive sandstone formations several hundred feet thick, is an excellent water carrier. At Lansing it was found to have a thickness of 1,000 feet. The Cambrian outcrops or lies immediately below the drift only in the valleys of Mississippi river and its immediate tributaries from the northern boundary of the state to McGregor in Clayton county, in the valley of the Oneota and its immediate tributaries in Allamakee county, and over an area of less than a square mile in Winneshiek county. It outcrops in all of these valleys only along the base of the high bluffs, where it has been exposed by the deep carving of ancient streams.

The Cambrian rocks of Iowa consist of certain undifferentiated sandstones, marls, and shales, at the base, above which lie the formations known, from the bottom up, as the Dresbach sandstone, the Saint Lawrence formation, and the Jordan sandstone.

[1]Rept. Iowa Geol. Survey, vol. 1, 1893, pp. 165-169; vol. 6, 1896, pp. 112, 180, 199.

DRESBACH SANDSTONE AND UNDERLYING CAMBRIAN STRATA.

DEFINITION.

In the senior writer's early investigations of Iowa deep wells the term "Basal sandstone" was used tentatively to include all Cambrian deposits below the base of the Saint Lawrence formation, since no term used by either the Minnesota or the Wisconsin surveys seemed sufficiently inclusive, the term Dresbach being employed by the Minnesota geologists to designate only the upper formation of the series of strata in question. Since that time the term Dresbach has been used loosely by some writers to include all the underlying Cambrian strata, but it is used in this report in the restricted sense, that is, for the sandstone exposed at Dresbach, that being the definition adopted by the United States Geological Survey. The Dresbach sandstone, which in the type region is a white, incoherent, fine-grained sandstone, is of Upper Cambrian age, whereas the underlying shales and sandstones are believed by geologists of the United States Geological Survey to belong to the Middle Cambrian.

DISTRIBUTION.

Sandstones referred by Calvin to the Dresbach outcrop in Iowa along the base of the Mississippi bluffs in Allamakee county from Lansing north to the state line.

It is quite possible, however, that these strata belong to the Saint Lawrence formation, and if this is true the Dresbach sandstone nowhere comes to the surface within the limits of the state.

At Dubuque (Pl. VI) the Dresbach and underlying Cambrian strata were sounded by the drill to a depth of 1,100 feet, the base of the Cambrian not being reached. Toward the west these strata seem to thin. In east-central Iowa their total thickness is 360 feet at Cedar Rapids (Pl. XI), and 463 feet at Tipton (Pl. X), not including the red clastic series (Algonkian?) already mentioned. In northwestern Iowa the Dresbach and underlying Cambrian strata probably thin rapidly as they rise on the western side of the median trough that traverses the state.

In central Iowa, at Des Moines and Boone (Pl. XVI), it is difficult to draw the line separating the Dresbach sandstone from the overlying Saint Lawrence formation.

LITHOLOGIC CHARACTER.

The Dresbach and the subjacent Cambrian strata include thick beds of sandstone of rolled grains of moderate coarseness, ranging in color from white to yellow and buff. These saccharoidal sandstones are pervious, especially in northeastern Iowa. Close-textured beds also occur whose pore spaces have been filled with limy cements. Sandstones are found whose angular grains of quartz are so minute and so closely packed that the rock must be well-nigh impermeable, and with these may be ranged marls, whose fine siliceous grains were mingled with mud and lime as they were laid on the sea floor. These marls and impure sandstones contain many dark green, round, subtranslucent grains of glauconite. Limestones are unknown. No order of succession has been made out for the beds. In several wells, as those at Dubuque, Manchester, Anamosa, and Tipton (Pls. VI, IX, X), the upper sandstone (Dresbach sandstone) rests on marls or arenaceous limy shales, which are in turn succeeded by heavy basal sandstones.

SAINT LAWRENCE FORMATION.

DISTRIBUTION.

On the Dresbach sandstone rests a heavy body of dolomite and shale, known as the Saint Lawrence formation, which outcrops as calcareous and sandy shales in the bluffs of the Mississippi in the northeastern county of the state. In eastern and north-central Iowa the limits of the formation are usually well drawn in deep-well sections, and its dual nature, dolomitic above and argillaceous below, is clearly seen. Southwestward the limits of the formation become difficult to trace, as the sandstones, both above and below, become more dolomitic or more clayey. At McGregor (Pl. V) the formation is represented by a few feet of arenaceous dolomite, left uneroded in the bottom of the preglacial channel of the Mississippi, and by 113 feet of green shale immediately subjacent. At Waverly (Pl. VII) and

Sumner the upper dolomitic beds are respectively 150 and 170 feet thick and the shales and marls beneath reach the surprising thickness of more than 300 feet. In each of these places sandy beds occur near the middle of the shales, and if the upper limit of the Dresbach were drawn at the summit of these sands the thickness of the shales left to the Saint Lawrence would accord with the thickness reported in other deep-well sections. At Charles City the formation was penetrated for probably 330 feet. (See Pl. V.) Owing to a gap in the record, the upper limit is not certainly known.

At Dubuque an imperfect record allows less than 200 feet for this formation. At Manchester it reaches a total of 242 feet. (See Pl. VI.) Southwest of Dubuque the massive basal shales and arenaceous marls fail to maintain themselves. At Anamosa (Pl. IX) the formation consists (from above down) of 145 feet of dolomite, 55 feet of shale, and 40 feet of dolomite. At Tipton (Pl. X) the Saint Lawrence embraces 120 feet of dolomite resting on 100 feet of marls. At Boone (Pl. XI) the discrimination of the Saint Lawrence is made, with much uncertainty, to include 285 feet of glauconiferous shales and marls and close-grained sandstones reaching nearly to the bottom of the well. At Des Moines (Pl. XIII) about 300 feet of similar strata, lying immediately below the Prairie du Chien, may be assigned to the Saint Lawrence with much hesitation.

LITHOLOGIC CHARACTER.

The upper dolomitic member of the Saint Lawrence is in places more or less arenaceous and commonly contains a good deal of finely divided angular quartzose material. Glauconite is present in many localities. The shales of the lower member are commonly somewhat calcareous and siliceous. The rocks, designated "marls," for want of a better term, consist of lime, silica, and clay and give rise to drillings of concreted gray, greenish, bluish, brown, or pink powder. The friability of the concreted mass indicates roughly the relative proportions of clay and sand, and the reaction with hydrochloric acid shows a large amount of lime and magnesian carbonates to be present in many places. The quartzose constituent is in the form of fine rounded grains and still more commonly of impalpably angular particles of crystalline quartz. Noncalcareous, plastic, pink, red, or green shales also occur, and in some places these are hard and fissile.

For these marls the characterization of Winchell of outcrops in Minnesota would seem applicable: "Greenish and shaly and yet not a shale; calcareous and not a limestone; magnesian but not a dolomite; finely siliceous but not a sandstone."[1]

JORDAN SANDSTONE.

DISTRIBUTION.

The Saint Lawrence formation is overlain by a sandstone called the Jordan, from the name of a town in Minnesota at which it outcrops. In Iowa it comes to the surface only in Allamakee, Winneshiek, and Clayton counties in the valleys of the Mississippi and its tributaries. In these outcrops it has two phases—a hard sandstone, whose grains are embedded in a dolomitic matrix, as at Lansing, and a soft stone, so destitute of limy cement that it can be readily excavated with pick and shovel, as at McGregor.

West of McGregor, as far at least as Charles City (Pl. V), it forms a well-defined bed about 75 feet thick, and to the southwest, at Waverly (Pl. VII) and Sumner, it is still thicker, reaching 110 feet or more. At Manchester (Pl. VI) it occurs as 86 feet of clean quartz sand, including four feet of highly arenaceous and calcareous shale. At Waterloo (Pl. VI) it attains a thickness of nearly 50 feet. At Anamosa (Pl. IX) it reaches nearly 100 feet, including calciferous sandstones, both above and below the main body of pure quartzose sandstone. At Monticello the drill penetrated it for 59 feet. At Cedar Rapids (Pl. XI) the data are very meager; but a distinct water-bearing sandstone, nearly 50 feet thick, is indicated at this horizon, with closer-textured sandstones in juxtaposition both above and below. At Ackley (Pl. VI) it is represented by calciferous sandstones. A gap occurs here of 100 feet, from which no drillings were saved.

In central Iowa either the limestones intervening between the Saint Peter and the Jordan greatly increase in thickness, or the

[1]Winchell, N. H., Geol. and Nat. Hist. Survey Minnesota, vol. 1, 1884, p. 255.

Jordan becomes indistinguishable in the rapidly changing assemblages of sandstones, dolomites, and shales which in this area pass downward from the Shakopee dolomite. If the former be true the Jordan is encountered at Ames (Pl. XI) 600 feet below the Saint Peter on a well-marked sandstone, 100 feet thick, composed of clean quartz in well-rolled grains. At Boone (Pl. XI), however, this horizon is held by sandstones, close textured and for the most part calciferous. At Des Moines (Pl. XIII) no attempt has been made to divide the Cambrian into the formations seen farther east. In southeast Iowa few deep wells reach the Jordan. At Burlington (Pl. XIII) the Jordan, if it is present, lies within a space of 300 feet from which no drillings were obtained; above this space the strata are clearly Prairie du Chien, and below it they are different beds of the Saint Lawrence or Dresbach facies. At Centerville (Pl. X) the magnesian series extends downward from the Saint Peter for more than 700 feet, without reaching any heavy sandstone comparable to the Jordan nor any glauconiferous shales or marls of the Saint Lawrence type.

LITHOLOGIC CHARACTER.

Typically the Jordan is a loose-textured sandstone consisting of rolled grains of clean quartz sand, white or light gray in color. In many places the grains are about as well sorted and as perfectly rounded and ground by abrasion as are the quartz spherules of the Saint Peter. In certain beds, however, dolomitic grains appear among the drillings, indicating either a calcareous matrix or thin interbedded layers of dolomite. The driller recognizes the Jordan by these characteristics and by its place as the first heavy sandstone below the Saint Peter, from which it is separated by an interval of not less than 300 feet.

ORDOVICIAN SYSTEM

PRAIRIE DU CHIEN STAGE.

Prairie du Chien stage is a term introduced into geologic literature in 1906 to designate the strata formerly called "Lower Magnesian limestone." This stage is divided, from the bottom up, into Oneota dolomite, New Richmond sandstone, and Shakopee dolomite. The New Richmond, however, is in many places ill defined or absent.

DISTRIBUTION.

The Prairie du Chien is a distinct cliff maker, and since it is both underlain and overlain by weak sandstones it rises in bold escarpments and castellated walls along Mississippi river and all of its tributaries from the northern boundary of the state nearly to Guttenberg. Owing also to its resistant quality it is distinctly an upland group of strata, and forms much of the country rock of Allamakee and northeastern Winneshiek counties. In the bold cliffs in which the Prairie du Chien outcrops at Prairie du Chien, Wisconsin, opposite McGregor, and to the north along the Mississippi and its tributaries, it has nowhere been found to measure more than 250 feet. In well sections, however, it appears as not less than 300 feet in thickness. In northeastern Iowa, where the dolomites are well demarked by the Saint Peter and Jordan sandstones, the Prairie du Chien varies in thickness between 300 and 400 feet. To the west in northern Iowa it maintains a thickness of 300 feet at Mason City (Pl. V) and of 375 feet at Ackley (Pl. VI). At Fort Dodge (Pl. VI) 300 feet may with certainty be assigned to this terrane. In central Iowa it seems to thicken and appears to reach 600 feet at Ames (Pl. XI) and nearly as much at Boone (Pl. XI); at Des Moines (Pl. XIII) it is probably 400 feet thick, although its base there can not be accurately determined. In southeastern Iowa, at Burlington (Pl. XIII), it can hardly measure less than 500 feet. At Centerville (Pl. X) more or less arenaceous dolomites of Prairie du Chien facies were still present when the drill had been driven 700 feet below the base of the Saint Peter, and neither clean sandstones nor glauconiferous shales were found to indicate that the Cambrian had been reached. South and west of Des Moines no wells have penetrated to this horizon.

LITHOLOGIC CHARACTER.

In all parts of Iowa, unless it be in the extreme northwest, wherever the drill has reached the horizon of the Prairie du Chien it has not failed to find it with the lithologic characteristics of its outcrop quite unchanged. Everywhere it is completely and perfectly dolomitized. Drillings are mostly in the form of gray or light buff, sparkling dolomitic sand. So hard is the rock that chips of any size are rarely preserved. When such are found they show a characteristic porous or vesicular texture. Heavy beds of dolomite occur which are quite free of arenaceous material, but with them are always to be found sandy dolomites and thin interbedded dolomites and sandstones. When a complete series of drillings is at hand the Prairie du Chien exhibits a rapid alternation of beds differing in their arenaceous content, and sections based on a few widely separated samples can not be reckoned reliable in detail. Quartz sand, native in part but no doubt also in part fallen from the Saint Peter, is so common in drillings from strata at this horizon that the rock is designated "sand and lime" in many drillers' logs. Chert is another invariable constituent of the Prairie du Chien. Usually white in color, it is not accompanied by the bluish translucent chalcedony characteristic of the geode beds of the Mississippian. In places a siliceous oolite is found, both in outcrops and in drillings; in the latter it is recognized by the white, round grains of chert broken from their matrix and showing concentric structure on fractured surfaces.

The sand grains of the Prairie du Chien are generally rounded, of clear quartz similar in facies to the Saint Peter and Jordan sandstones. The New Richmond sandstone, however, in many places displays, both in outcrops and in well drillings, grains which under the microscope show pyramidal secondary enlargements of crystalline silica in optical continuity with the original grains. These crystal facets give a distinctive sparkle to the sand in mass.

Along with these typical features of the Prairie du Chien are others that are local and exceptional. Such are marly beds, which yield drillings of whitish gray or pink powder that effervesces freely in strong hydrochloric acid, leaving a clayey and minutely quartzose residue. Thin beds of green or red shales occur in some places. Especially worthy of note is a sandy shale found in places as the upper part of the Shakopee dolomite immediately underlying the Saint Peter sandstone; at

Boone (Pl. XI) this shale is 10 feet thick and at Anamosa 40 feet (Pl. IX). The Shakopee is distinctly argillaceous at Belle Plaine. At Holstein a red caving shale occurs 20 feet below the bottom of the Saint Peter; and at Sanborn, according to the driller's log, shale and sand extend for 200 feet below this level. (See Pl. XVII.)

A wholly exceptional facies is that shown in a drill hole sunk for oil near Maquoketa (Pl. X), the driller's log of which states that for 241 feet below the Saint Peter there extends a brick-red argillaceous sandstone, of fine, rounded grains, including seams of red shale. As only one sample was supplied for the entire 241 feet, it was the writer's first impression that the drilling might have been colored by particles resulting from the continuous caving in of a comparatively thin bed of red shale situated near the top of the Shakopee. But the log was made out with unusual care by the foreman in charge of the work, and an inspection of the discharge from the sand pump, made after the work was nearly done, showed so large an amount of the red sandstone as to give much support to the statement of the log. If the unconformity believed by some geologists to exist between the Shakopee and the Saint Peter is found in eastern Iowa, the sandstone in question may be a continental deposit in a small trough or basin, covered on subsidence by the Saint Peter sandstone. So unlike is it to any other body of rock belonging to the Saint Peter or the Shakopee in Iowa that the writer has not classed it with either terrane.

The presence of rocks of reddish color underneath the Saint Peter is reported in a number of wells in Minnesota and Illinois, though never to such a thickness as at Maquoketa. Thus in Minnesota the deep well at East Minneapolis shows 102 feet of red limestone at this horizon,[1] and the well at the West Hotel[1] a dolomitic limestone 82 feet thick, reddish in color at top. In Illinois a red marl immediately subjacent to the Saint Peter is reported as 32 feet thick at Lake Bluff,[2] 45 feet thick at Winnetka,[2] and 40 feet thick at Joliet.[3] At the paper mill at Moline "red marl and limestone" 316 feet thick is reported at this

[1]Hall, C. W., Bull. Minnesota Acad. Nat. Sci., vol. 3, p. 139.
[2]Stone, Leander, Bull. Chicago Acad. Sci., vol. 1, p. 96, 1886.
[3]Leverett, Frank, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 799.

horizon, and at the East Moline well the Saint Peter is underlain by 105 feet of limestone resting on 35 feet of red marl.[1]

If the red argillaceous sandstone at Maquoketa be not a continental deposit, it must be placed with the Shakopee.

SAINT PETER SANDSTONE.

DISTRIBUTION.

The Saint Peter sandstone, which overlies the Prairie du Chien stage, is one of the most remarkable water-bearing formations of the state. Owing to its slight resistence to weathering and erosion it outcrops only in a narrow, sinuous belt about the outer margin of the Prairie du Chien. In the valley of Mississippi river it is seen in the sides of the bluffs as far south as Dubuque, and in the valley of Oneota river and its tributaries it extends a short distance into Winneshiek county. Its chief exposures are, however, in Allamakee county. It consists of a bed of sandstone, normally white but in many places stained with iron oxides, which reaches a thickness of 70 to 100 feet. The thickness of the formation, as disclosed by the deep wells of Iowa, differs widely, though not so widely as in Wisconsin, where, owing to the irregular surface of the Shakopee, on which the Saint Peter was laid, it ranges in thickness from 200 feet in troughs to an exceedingly thin layer on crests of the underlying dolomites. In the Iowa wells the maximum reported thickness is 110 feet at Emmetsburg (Pl. XVI) and the minimum 15 feet at Pella (Pl. XIV).

The Saint Peter probably underlies the entire state, except the extreme northwestern part. In the southwestern part it has not yet been reached, but its recognition at Lincoln, Nebraska,[2] and at different places in Missouri makes its presence there not improbable.

The Saint Peter reaches its highest elevation in Allamakee county, where it lies not far from 1,200 feet above sea level. It sinks continuously to the southwest, and at Des Moines, where last found in deep drilling (Pl. XVI), it lies at 1,114 feet below sea level, or more than 2,300 feet below its elevation in the north-

[1]Udden, J. A., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 848.
[2]Sixth Bienn. Rept. Nebraska Commissioners Public Lands and Buildings, 1888, pp. 59-84.

east corner of the state. In northern Iowa it dips both from the east and from the west toward the median line of the great syncline of the Paleozoic strata, and in southeastern Iowa it rises in the Ordovician dome, so that it stands higher at Burlington and Keokuk than at Davenport and Mount Pleasant. The formation is so important, being the first of the great series of water-bearing beds which constitute the aquifers of the Iowa artesian system, and it is so easily recognized by the driller and the layman, that its elevation above sea level is presented on the map (Pl. I, in pocket).

LITHOLOGIC CHARACTER.

In its outcrops the Saint Peter is a massive homogeneous bed of sand, so loosely cemented that it is readily excavated with the spade. Hand specimens of any size are difficult to obtain. No traces of lamination or oblique stratification appear, and the few ill-defined bedding planes are 10 to 15 feet apart.

The individual grains are exceptionally uniform in size. They are of clear quartz, worn no doubt from the crystalline grains of acidic igneous rocks and representing the survival of the hardest. In this respect they differ from the varicolored grains of the Dakota sandstone and the sand beds of the drift. They are also remarkable for the perfection of their rounding. The smoothness of these spherules and their "millet seed" appearance suggest that they suffered long attrition under the winds of ancient deserts before they were deposited in the sea. Their shape distinguishes them from the subangular sands of the Coal Measures and from the faceted grains of the New Richmond, as well as from those Cambrian sandstones that are composed of minute angular particles of quartz.

The transition from the Saint Peter, either to the beds above it or to those below, is not everywhere abrupt. Arenaceous shales may intervene between it and the Shakopee dolomites, and still more commonly the Shakopee seems to include thin beds of sandstone. These sandy beds were noted in the field by McGee, and led him to classify the Shakopee as a part of the Saint Peter.[1]

[1]McGee, W J; Eleventh Ann. Rept. U. S. G. S., 1889-1890, pt. 1, p. 332.

To recognize such sand beds in the drillings of deep wells is far more difficult, but probably the considerable amount of quartz sand in many wells, mingled with dolomitic chips from the Shakopee, comes from intercalated sandstone beds rather than from above or from sand disseminated throughout the limestone. At Boone and Sabula the Saint Peter apparently includes intercalated beds of sandy shale. The Saint Peter is also in places overlain by transitional sandy shales and limestones, the deposition of which in some areas inaugurated the Platteville epoch. At Des Moines a brown arenaceous dolomite, 30 feet thick, is parted from the Saint Peter by a hard green shale 10 feet thick. (See Pl. XIII.) At Washington (Pl. X) the Saint Peter is overlain by a thin bed of sandy shale. At Charles City (Pl. V) a stratum, 70 feet thick, of fine-grained argillaceous sandstone rests on Saint Peter of normal facies. At Mason City (Pl. V) a yellow, highly arenaceous dolomite 20 feet thick, and at Belle Plaine (Pl. VIII) a thin bed of arenaceous limestone occupy this horizon. At Postville (Pl. V) the Saint Peter was apparently encountered at 755 feet above sea level; but, after passing through 14 feet of this sandstone, the drill entered limestone of Platteville facies, in which it continued to 689 feet above sea level, when it reached an arenaceous, nondolomitic limestone, which continued 13 feet to the bottom of the boring. If studied in the field, it is probable that some of these arenaceous transition beds would be classed with the Saint Peter, but for the purposes of this investigation it has seemed better to place them with the superjacent or subjacent formations.

ROCKS BETWEEN THE SAINT PETER SANDSTONE AND THE MAQUOKETA SHALE.

SUBDIVISIONS.

Upon the Saint Peter sandstone rests a series of limestones, shales, and dolomites which extends upward to the base of the Maquoketa shale. The upper dolomitized beds of this series have long been known as the Galena dolomite, while the lower limestone and shales have usually been termed the "Trenton." In the report of the senior author of the artesian wells of Iowa[1]

[1]Rept. Iowa Geol. Survey, vol. 6, 1896, pp. 145 ff.

the entire series was treated as a single formation, called the "Galena-Trenton," whose strata were shown to be affected by dolomitization to varying depths at different places. Since the publication of this report an intermediate formation, the Decorah shale, has been discriminated. The calcareous beds which overlie the Decorah shale are now known as the "Galena dolomite," while the limestones and shales which intervene between the Decorah shale and the Saint Peter sandstone are termed the "Platteville limestone." These formations rise to the surface in northeastern Iowa in a very broken and irregular area, which extends from the northwestern part of Winneshiek county as far south as Bellevue in Jackson county.

PLATTEVILLE LIMESTONE AND DECORAH SHALE.

In well sections the Platteville is singularly persistent. It embraces a shale bed immediately overlying the Saint Peter—the Glenwood shale of the Iowa State Survey—and an overlying body of limestone. Few well sections in Iowa reach the horizon of the Saint Peter without finding either this basal shale of the Platteville or the higher Decorah shale, although in many wells the three divisions can not be made out.

The shales of the Platteville limestone and the Decorah shale are typically rather harder, darker, and a brighter green than the Maquoketa shale. Even where no record or sample of them is preserved characteristic chips, evidently fallen from above, are sometimes brought up from lower levels. At Manchester (Pl. VI) both the Decorah shale and the basal shale of the Platteville were found, the Decorah being five feet thick and carrying *Orthis perveta* Conrad, *Strophomena trentonensis* W. & S., and several Bryozoa. A body of typical earthy blue-gray Platteville limestone, 72 feet thick, here intervenes between the two beds of shale, the lower one of which is only seven feet thick. In northern Iowa, at Hampton, the basal shale of the Platteville is 40 feet thick; at Charles City (Pl. V) 70 feet of arenaceous shales are overlain by 90 feet of more typical shale; at Waverly (Pl. VII), Sumner, Maquoketa (Pl. X) and Clinton (Pl. XI), the Platteville limestone and Decorah shale are well exhibited, their total thickness in the last two places measuring about 100 feet, including the shale at the base of the Platteville. In northwestern Iowa the basal shale of the Platteville reaches 50 feet at Sanborn (Pl. XVII), 95 feet at Emmetsburg (Pl. XVI), 110 feet at Mallard (Pl. XVI), and somewhat less than 50 feet at Cherokee and Holstein (Pl. XVII). At Des Moines the basal shale member of the Platteville is also present, and the Platteville and Decorah have a combined thickness of 50 feet (Pl. XVI), but the limestone of the Platteville is exceptional in that it is dolomitic. In southeastern Iowa the Platteville reaches a thickness of 90 feet at Pella and 100 feet at Burlington. (See Pl. XIII.)

The Decorah shale extends to the extreme southwest corner of the state; for in the deep boring at Nebraska City, Nebraska, it was found at a depth of 2,754 feet, and its identification by stratigraphic and lithologic characteristics was amply confirmed by Ulrich's determination of the distinctive fossils *Stictopora angularis* and *Dalmanella subaequata* var. *minneapolis* (?).

In a number of places the Platteville limestone includes a brown bituminous shale from which the drill chips fragments that readily give forth long flames when ignited. This is the case at the Platteville outcrops near Dubuque. In southeastern Iowa this bituminous shale occurs at Pella, Letts, Washington, and Burlington. Its presence is of special interest, for it is from this horizon that the natural gas and petroleum of some large fields in other states rise to be stored in the reservoirs of overlying rocks. The presence of bituminous shale or other bituminous rock as a source is but one of the conditions for the accumulation of these illuminants in paying quantities. As no oil or gas has been found in the wells which reach the Platteville, even where the formation is bituminous, it is evident that some of the other equally necessary conditions do not exist in Iowa in any area yet explored.

The limestone of the Platteville is typically compact, blue or gray, more or less argillaceous, and in many places fossiliferous; under the drill it is broken to rather large flaky chips of earthy luster. The magnesian content is not sufficient to prevent brisk effervescence in cold dilute hydrochloric acid.

In places the Decorah shale is lacking or unreported, and here no definite boundary can be drawn between the Platteville limestone and the overlying Galena dolomite.

GALENA DOLOMITE.

The Decorah shale is overlain by a heavy body of limestone or dolomite, known as the Galena dolomite, which extends upward to the base of the Maquoketa shale. In its outcrops in Dubuque county, where it is a marked cliff maker along the bluffs of the Mississippi river and its tributaries, the Galena is known as the lead-bearing rock, and is a rough, vesicular, buff, cherty and crystalline dolomite. More or less of the formation is completely dolomitized in other counties of its outcrop in northeastern Iowa, but dolomitization is by no means universal. In well sections the formation varies, at the same horizons. from a rather soft nonmagnesian limestone similar to the Platteville to a crystalline dolomite entirely similar to those of its outcrops near Dubuque. Thus in passing from Dubuque 40 miles west to Manchester the Galena changes from a homogeneous body of heavily bedded dolomite fronting the Mississippi in a wall 250 feet high to a series of thin-bedded, earthy, blue and gray limestones. Dolomite is absent also at Waterloo and Waverly. Where only a part of the formation is dolomitized, as at Sumner, Charles City, and Hampton, it is generally the upper portion. Dolomitic beds are present at Anamosa, Monticello, Clinton, Cedar Rapids, Tipton, Boone, and Fort Dodge. West of Des Moines river only dolomites occur in the samples of the drillings of this terrane. In central Iowa the formation is wholly dolomitic and in southeastern Iowa either the entire formation or the great bulk of it is either dolomitized or is crystalline and strongly magnesian.

THICKNESS OF THE PLATTEVILLE, DECORAH, AND GALENA FORMATIONS.

In northeastern Iowa the Galena, Decorah, and Platteville formations have a combined thickness ranging from 300 to 350 feet. At Vinton their combined thickness is 401 feet, and at Waverly it is 420 feet. In northern Iowa these formations persist far to the west. At Charles City (Pl. V) they together measure 380 feet, at Mason City (Pl. V) 405 feet, at Mallard (Pl. XVI) 375 feet, and at Emmetsburg (Pl. XVI) hardly less than 300 feet. At Osage (Pl. VII) they appear to be about 500 feet thick, but the apparent increase is probably caused by including dolomitic portions of the Maquoketa. At Holstein magnesian limestones at this horizon aggregate 500 feet in thickness, and at Cherokee they measure 300 feet. (See Pl. XVII.) In the extreme northwestern part of Iowa the formations appear to thin and may feather out. At Sanborn (Pl. XVII) the driller's log places a bed 50 feet thick of "shale with streaks of rock" immediately above the Saint Peter, and this bed may represent the entire thickness of the three formations, Galena, Decorah, and Platteville. In central Iowa the combined thickness probably attains its maximum, measuring 410 feet at Boone and 508 feet at Des Moines. (See Pl. XVI.) In southeastern Iowa it thins markedly. At Pella the beds measure 350 feet, at Burlington 273 feet, and at Mount Pleasant 256 feet. (See Pl. XIII.)

MAQUOKETA SHALE.

DISTRIBUTION.

The heavy bed of dark bluish gray clay shale overlying the Galena dolomite is known as the Maquoketa shale. It forms a thin surface cover over the Galena in a broad but broken belt across Winneshiek and Clayton counties, and it outcrops here and there along Mississippi river and its tributaries as far south as Clinton. It disintegrates so rapidly as to allow the massive overlying Niagaran limestone to form a bold mural escarpment extending along the entire length of Turkey river on the western side—an escarpment that clearly marks not only the south and west limits of the Maquoketa as country rock but also fixes the western boundary of formations of the Cambrian and Ordovician rocks.

The Maquoketa varies greatly along its narrow outcrop from Clinton northwest to the Minnesota line. To the southeast it is a heavy body of shale. Thickening to the northwest, it comes to include an upper shale 125 feet thick, a medial bed of cherty magnesian limestone in places 50 feet thick, and lower beds of shales and shaly limestones which may locally attain a thickness of 100 feet; in well sections this triple division, which was perhaps first observed in this investigation, is well demarked. Again, in many well, as in its outcrops in Jackson and Clinton counties, the formation may be a single undivided body of shale. The tripartite division obtains in northeastern Iowa and extends west at least as far as Ackley. Thus at Sumner the Upper Maquoketa measures 80 feet, the Middle 70 feet, and the Lower 50 feet. At Manchester (Pl. VI) the median bed is represented by a thin bed of limestone situated about 50 feet from the bottom of the terrane. At Waterloo (Pl. VI) the upper beds are 160 feet thick, the middle 75 feet, and the lower 30 feet. At Charles City (Pl. V) the Middle Maquoketa is 30 feet thick, and at Ackley 21 feet (Pl. VI). At Hampton the main body of shale is as usual the Upper Maquoketa, and below it are ranged alternately two beds of limestone and two of shale, each about 20 feet thick. At Fort Dodge also beds of limestone occur at several horizons within the supposed limits of the formation. Southward from northeastern Iowa the Maquoketa appears as an undivided body of shale, as might have been expected from the disappearance of its median limestones along its southern outcrops.

LITHOLOGIC CHARACTER.

The shales of the Maquoketa are both softer and paler than the Cambrian shales, and they lack the arenaceous content found in many places in the latter. Their bluish rather than greenish tint helps to distinguish them from the Decorah shale. They are not arenaceous, as are some of the Mississippian shales, and the absence of carbon and the presence of lime serve to distinguish them from many of the Pennsylvanian shales. They resemble most nearly the shales of the Kinderhook stage (Lower Mississippian). Drillers know them by the forcible and not inappropriate term of "mud-rock" shales, since they appear in the slush bucket as a blue mud. Drillings are preserved in hard molded masses of concreted clay, gritless but calcareous and magnesian. In places the Maquoketa is highly pyritiferous. It includes in some areas bituminous brown shales. These are found near the base of the formation in the wells at Monticello, Tipton and Anamosa, and in the drill hole near Maquoketa sunk for oil. This drill hole was sunk because of a show of oil found on the surface of a spring, or sink-hole pool, near the site where the well was afterwards drilled, and if this crude petroleum was derived from any subterranean source it probably came from the Maquoketa horizon. At Grinnell (Pl. XV) bituminous shales 20 feet thick occur 70 feet below the assigned top of this formation.

SILURIAN SYSTEM

NIAGARAN DOLOMITE.

DISTRIBUTION.

Among the best water-bearing rocks of eastern Iowa must be ranked the Niagaran dolomite, the only formation of Silurian age that outcrops in the state. Beginning at the prominent Niagaran escarpment which borders Turkey river along its entire course, filling the great eastern bend of Mississippi river to Davenport, and lying east of a slightly irregular line drawn from West Union to Muscatine stretches the area over which this limestone outcrops or lies immediately below the drift.

LITHOLOGIC CHARACTER.

Except at one or two localities the Niagaran is completely dolomitized. Chert is not uncommon, especially in the lower beds. Minor differences in color and texture characteristic of the subdivisions of the Niagaran can seldom be discriminated in well drillings. Lithologically, the Niagaran of wells situated near its outcrops and for some distance west is a light buff, gray, or bluish dolomite, commonly subcrystalline and vesicular. Under the drill it may be crushed to sparkling sand and drillers may therefore report it in well logs as "sand rock."

Field surveys have shown that the Silurian pinches out in northern Iowa until the Devonian overlaps upon the Maquoketa shale, and the same condition is found in wells. The formation at the Tipton outcrop is 325 feet thick, but at Waterloo it has thinned to 107 feet and at Waverly to 50 feet. (See Pl. VII.) At Osage (Pl. VII) but 150 feet seems to be left for the combined thickness of both Silurian and Devonian. At Hampton but 80 feet can be allowed for the Niagaran. At Charles City (Pl. V) the Silurian may reach 180 feet, but as the rocks assigned to this horizon are not lithologically characteristic the estimate may be a good deal too large and may include some rocks properly belonging either to the Maquoketa or to the Devonian.

West of its area of outcrop the Silurian suffers lithologic changes which make its boundaries in many places difficult to determine. Thus, at Charles City (Pl. V) it is supposed to include a considerable amount of more or less argillaceous limestones that can hardly be assigned to the Maquoketa, because they would increase its thickness beyond probable measures. Westward from Cedar Rapids, along the line of the Chicago & North Western railway, the Niagaran facies is retained at Belle Plaine, where the formation measures 345 feet. (See Pl. XI.) At Marshalltown the Silurian is diminished to about 300 feet and includes brown magnesian limestones and nonmagnesian cherty limestones; several samples show more or less gypsum. At Ames and Boone the Silurian includes dolomites, thin shales, and more or less magnesian sandstones and limestones, the upper limit being drawn with great uncertainty, chiefly on stratigraphic evidence. At Ackley the Niagaran comprises about 180 feet of dolomite, but at Fort Dodge, farther west, the strata have so changed lithologically that the summit of the Silurian is very uncertain. (See Pl. VI.)

In southeastern Iowa the Silurian includes a calciferous sandstone, which at Washington is reported to be 100 feet thick. At Des Moines (Pl. XVI) arenaceous beds occur near the base of the terrane; at Centerville they are 50 feet thick and are composed of fine grains of clear quartz, moderately well rounded and sorted, many grains showing secondary enlargements whose facets give a peculiar sparkle to the drillings. Beneath this sandstone lies 60 feet of sandy limestone. At Ottumwa a sandy limestone is reported at about this horizon.

SALINA (?) FORMATION.

LITHOLOGIC CHARACTER.

West and south of its outcrops the Silurian comprises an assemblage of limestones and in places red, ferruginous, gypsiferous marls and beds of anhydrite, which seem best tentatively referred to the Salina, although this terrane has not been positively identified west of the Great Lakes. Gypsum and anhydrite are uncommon in the rocks of Iowa. Isolated crystals of selenite are present in some of the shales and beds of gypsum occur in the Permian deposits of Webster county and in the Saint Louis strata of Appanoose county. Both of these horizons are too high to be correlated with the gypsum deposits found in the deep wells. Apart from these two horizons drillings from Iowa wells have shown gypsum or anhydrite only at the horizon attributed for good stratigraphic reasons to the Silurian. In this system, however, these minerals are in places too conspicuous to escape notice. Bits of white gypsum or of the harder anhydrite are readily noted among the limestone chips. The whole content of the slush bucket may be a whitish mud concreting to tough masses quite unlike marls of similar color. Under the microscope many specimens show a field largely occupied with broken crystals of gypsum or anhydrite, whose identity is recognized unmistakably by their brilliant colors under polarized light and by their distinctive cleavages. Chemical tests confirm these observations.

DISTRIBUTION.

These deposits are assuredly Silurian at Marshalltown, where the Niagaran outcrop is but 75 miles to the east. In central and southern Iowa the presence of the Kinderhook above these beds and of the Maquoketa shale below them limits their horizon to either the Devonian or the Silurian. It is most unlikely that they can belong to both, and between the two the choice is not difficult. The absence of such beds from the Devonian elsewhere, their common presence in the Salina of the eastern United States, and other stratigraphic reasons leave little doubt that the beds in question belong to the Silurian and are of Salina age. The presence of a bed of gypsum may therefore be used as a means of correlation. At Des Moines, for example, where 588 feet of limestone lies between the base of the Kinderhook and the summit of the Maquoketa, the presence of gypsum 80 feet from the top and of well-marked beds below leaves not more than 80 feet to the Devonian and more than 500 feet to the Silurian. (See Pl. XV.) On the same assumption, the Silurian at Grinnell is assigned 414 feet, the gypsum beds being confined to the upper 247 feet; at Pella it is assigned 255 feet (Pl. XIII), and at Mount Pleasant, where the anhydrite beds are especially well marked, about 100 feet. The uncommon thickness thus alloted to the Silurian at Des Moines and Grinnell leads to drawing the boundary between the Silurian and Devonian higher at neighboring points, as at Boone and Ames, than might otherwise be done. (See Pl. XI.)

If the sub-Mississippian gypsum of central and eastern Iowa is considered Silurian, the horizon of the gypseous beds found in southwestern Iowa below the Carboniferous may also be referred to the Silurian; but the area is so remote from the outcrops of the terranes below the Pennsylvanian, and deep wells are so few, that the geologic sections in the few deep drill holes that pass below the floor of the Pennsylvanian can be made out only with the greatest difficulty. In the well at Glenwood (Pl. XVIII) a 70-foot bed of gypseous limestones and shales was struck at a depth of 1,924 feet. If 262 feet of superjacent dolomites and magnesian limestones and an included bed of sandstone are added, the Silurian will have a probable thickness of 332 feet. At Bedford, 60 miles southeast of Glenwood, beds of gypseous marl and limestone begin at 2,005 feet from the surface and continue to at least 2,350 feet. It is interesting to note that here ferruginous red and pink limestones occur above the gypseous beds, tending to confirm the suggestion that these beds represent the deposits of the arid climate of the Salina epoch. At Council Bluffs magnesian limestones referred to the Silurian and destitute of gypsum form the chief bed.

Though the Silurian as a whole thins out in northeastern Iowa, it thickens toward central Iowa, maintaining a thickness of more than 300 feet to the southwestern border of the state.

In southeastern Iowa the local upwarp of the lower Ordovician strata causes a notable thinning of the Silurian beds toward the dome. Thus the Silurian at Davenport, 345 feet thick, thins to some undetermined part of the 180 feet allotted to the combined Devonian and Silurian at Burlington and to a probable 60 feet at Keokuk. (See Pl. XII.) At Pella the thickness of the combined Silurian and Devonian is 420 feet, at Mount

Pleasant it is about half that measure, and at Burlington it is compassed within 180 feet. (See Pl. XIII.) The thickness of the Silurian and Devonian at Centerville is nearly 400 feet (Pl. X); 80 miles east of Centerville, at Fort Madison, it measures only 142 feet (Pl. XII).

DEVONIAN SYSTEM

The Devonian limestones and shales occupy a wedge-shaped area whose wide base lies along the northern boundary of the state from Winnebago county to Howard county. Pointing southeastward and gradually narrowing, it comes to an apex in Scott and Muscatine counties. The Devonian includes rocks formed during three principal epochs. The uppermost formation, the Lime Creek shale, which is of Upper Devonian age, is typically exposed in Cerro Gordo and adjoining counties, where it comprises blue and yellow shale (the Hackberry substage of the Iowa State Survey) 70 feet thick, overlain by dolomite and shale (the Owen substage of the Iowa Survey) exceeding 50 feet in thickness.

In other parts of the state the uppermost Devonian formation is known as the Sweetland Creek shale, and in still other areas it is represented by the State Quarry limestone of the Iowa Survey reports. These three formations have been regarded as more or less contemporaneous. Each rests unconformably upon the Cedar Valley limestone. The medial formation of the Devonian—the Cedar Valley limestone—is of Middle Devonian age, and is the most widely distributed of the three. It comprises an assemblage of limestones varying widely in color and texture and argillaceous content, and in the northern counties includes dolomitic beds, but over most of the area the magnesian content falls far short of that requisite for dolomite. The thickness of the Cedar Valley limestone in Johnson county is estimated at 104 feet by Calvin. The lowest Devonian formation—the Wapsipinicon limestone—is also of Middle Devonian age. It consists of blue and yellow shales, cherty argillaceous limestones, local beds of coal and coaly shales (the Independence shale), gray lithographic limestones and breccia beds along with limestones of other types. The lowest beds of the Wapsipinicon are dolomitized and can not always be distinguished in drillings from the Silurian dolomites.

These Devonian formations can be distinguished from each other in some deep wells, but as a rule they can not be separated, and it is with considerable difficulty that even the limits of the Devonian as a whole are drawn. Thus the highest shale of the Devonian may be immediately overlain by shale of the Kinderhook group. Where this occurs and fossils are absent, the discrimination has been found impracticable even in outcrops. Certain shales in a well at Hampton are classified as Devonian rather than Kinderhook, owing to their stratigraphic correspondence with certain heavy shales, apparently Devonian, that outcrop at Sheffield. At Belle Plaine the highest shales of the section are placed with the Devonian only because of the general dip of the strata of the region. (See Pl. XI.) Apparently there is in central Iowa a strong development of the Lime Creek shale, but it can be separated from the Kinderhook only by more or less arbitrary lines, drawn by the accepted areal distribution and the supposed dip of the strata.

In discriminating the dolomitic beds of the Devonian from those of the Silurian, the Silurian beds, except those of northeastern Iowa, are generally considered the more persistent and the heavier. Though the area of outcrop of the Devonian is wide, measuring about 75 miles on the north from east to west, the thickness of the terrane at any point on the area of outcrop is not large. At Waverly (Pl. VII) a well section shows a total thickness of only 70 feet of Devonian rocks, above which the natural outcrops rise some 50 feet higher.

The greatest thickness attributed to the Devonian is at Marshalltown (Pl. XI), Ackley (Pl. VI), and Hampton, where it seems to reach 300 feet. At Grinnell (Pl. XV) it is given as about 200 feet and is largely shaly. At Homestead (Pl. XV) heavy shales below the drift lie at the Devonian horizon, but if there is here a downwarp, the shales may be Kinderhook instead. In southeastern Iowa the Devonian nowhere reaches more than 175 feet in thickness. At Washington (Pl. X) 100 feet can be assigned to it with some certainty. At Letts (Pl.

XIV), Mount Pleasant (Pl. XIII), and Burlington the Devonian somewhat exceeds 100 feet, and at Pella and Sigourney (Pl. XIV) it reaches about 170 feet. In several instances, however, the rocks ascribed to the Devonian may include more or less of the basal portion of the heavy shales whose main body is unquestionably Kinderhook.

CARBONIFEROUS SYSTEM

MISSISSIPPIAN SERIES.

OUTCROPS AND SUBDIVISIONS.

Mississippian (Lower Carboniferous) rocks outcrop along a belt of varying width extending from Kossuth and Winnebago counties on the north to Mississippi river on the southeast, and along the river from Louisa county to the Missouri state line. The series embraces a wide variety of rocks. With two or three exceptions its formations are not thick, and in well sections lithologic change is comparatively rapid.

The Mississippian of the Iowa State Survey reports, and as used in this report, comprises three major subdivisions which, from the base upward, are known as the Kinderhook stage, the Osage stage, and the Saint Louis limestone. The Osage stage of this report, however, is not exactly the same as the Osage stage of the United States Geological Survey, since, for convenience, the former includes at the top the lower part of the Warsaw limestone, the upper part of the Warsaw being included in the overlying Saint Louis limestone, as that formation is defined in this report.

KINDERHOOK STAGE.

The Kinderhook stage embraces a median heavy shale with limestones above and below. In central Iowa the upper non-argillaceous beds are strongly developed and furnish the white oolitic and buff magnesian limestones of Tama, Marshall, Franklin, and Humboldt counties. In well sections it is quite impossible to discriminate any basal limestones from those of the Devonian, and it is in many places equally impracticable to discriminate the upper limestones of the Kinderhook from the overlying Osage limestones. The main body of shale, however, is one of the best defined in the state, especially in southeastern Iowa. At Burlington, Mount Clara, and Mount Pleasant it runs from 300 to 370 feet in thickness; at Fort Madison it is 268 feet thick, and at Keokuk about 225 feet. (See Pl. XII.) North and west from its outcrop in the extreme southeastern part of Iowa, the shale thins somewhat. At Ottumwa (Pl. X) it measures 165 feet, at Grinnell (Pl. VIII) 170 feet, at Sigourney (Pl. XIV) 198 feet, at Pella and at Oskaloosa less than 125 feet. (See Pl. XIII.) In central and northern Iowa, as on the uplands of southeastern Iowa, the shales of the Kinderhook generally fail of exposure, as in preglacial time their outcrop formed a belt of weak rock wasting to lower levels than the area of stronger rock adjacent, and during the Pleistocene this trough was deeply filled with drift. The absence of rock exposures along a belt of considerable width bordering the line of the westernmost Devonian outcrops may thus be explained.

In central Iowa the chief beds of the Kinderhook which reach the surface are limestones. The section at Marshalltown (Pl. XI) discloses a thickness of 145 feet for this division of the Kinderhook and of 175 feet of underlying shales. At Ackley (Pl. VI) 207 feet of shale seems to belong to the Kinderhook. At Hampton the 108 feet of shales immediately below the drift falls into two divisions and, according to Williams,[1] the same beds occur at several points in the eastern part of the county, giving rise to a line of springs.

West of a line passing through Marshalltown, Ackley, and Hampton the shales of the Kinderhook greatly diminish in thickness. They are so scant at Ames, Boone, and Fort Dodge that the boundaries of the Kinderhook are drawn with greatest difficulty. At Dayton they are wholly absent so far as the record shows, although it is possible that the well may have failed of reaching them by a few feet. Both at Boone and Fort Dodge the base of the Kinderhook is arbitrarily drawn at a bed of thin shales lying underneath argillaceous limestones. (See Pl. XVI.)

In southwestern Iowa, at Glenwood, shales 134 feet thick occur at the supposed base of the Mississippian, and at Bedford shales thirty feet thick are found at this horizon. (See Pl. XVIII.)

[1]Williams, I. A., Ann. Rept. Iowa Geol. Survey, vol. 16, 1906, p. 482.

OSAGE STAGE.

The rocks of the Osage stage immediately overlie the Kinderhook. The basal limestones of the Osage are well known to all drillers in southeastern Iowa as the Burlington limestone. Under the drill they break into flaky chips, many of which are intensely white. Close examination shows that the apparent crystalline structure of many specimens is due to the crystalline cleavages of the broken plates and stem joints of crinoids. In places the stone is made up almost wholly of crinoidal fragments, and where finer cementing material is wanting the rock becomes full of interstices and permeable to water. The lower strata of the Burlington are somewhat thickly bedded with thin partings. Toward the top they include chert and brown siliceous shales. The overlying beds of the Burlington are less massive and in many places parted by shaly layers. These beds pass upward into cherts (the Montrose Chert of the Iowa Geological Survey), which form the top member of the Burlington and which outcrop along the bed of the Mississippi, giving rise by their hardness to the Des Moines Rapids, which extend from Montrose to Keokuk. Hard and resistant to the weather as these cherts are, they present no special difficulty to the experienced driller, for they are brittle, breaking easily under the stroke of the drill, and their angular white chips do not pack. They occur either irregularly bedded in shattered seams or so disposed in nodules that the solution of the limy content of the strata leaves them highly permeable and serviceable as water beds.

On account of their purity the limestones of the Burlington are highly soluble. Sink holes along the outcrops indicate where the run-off flows rapidly down to subterranean channels excavated by solution along bedding planes and joints.

Above the Burlington limestone the Osage stage includes cherty coarse-grained limestone and limy shales (Keokuk limestone), which at their outcrop abound in geodes—hollow shells of chalcedony or of lime carbonate lined with crystals of quartz or calcite. The presence of this formation is in some places indicated to the driller by chips of milky chalcedony and pieces of broken crystals of clear quartz brought up in the slush bucket in some abundance. For convenience the lower part of the Warsaw limestone is included in the Osage stage of this report.

SAINT LOUIS STAGE.

The Saint Louis limestone, the uppermost division of the Mississippian as here differentiated, forms an important part of the country rock over Keokuk, Washington, Henry, and Lee counties, over minor areas in adjacent counties, and over Story, Webster, and Humboldt counties. Its lowest division consists of shale and shaly limestones, which properly belong to the Warsaw limestone, but which for convenience are included in the Saint Louis. A median division consists of gray sandstones, shales, and brecciated limestones, the sandstones predominating. The upper division is made up largely of heavily bedded, impure magnesian limestones with some marls. These different subdivisions are distinguished in the shallower wells of the region of outcrop, but have not been traced to any distance from their outcrop by means of the deeper wells.

THICKNESS OF OSAGE STAGE AND SAINT LOUIS LIMESTONE.

The geologic sections (Pls. V-XVIII) show that the combined thickness of the Osage stage and Saint Louis limestone as differentiated in this report varies within wide limits. The upper surface of the Mississippian is everywhere a surface of erosion, not only along its outcrops, but also where it is parted by a strong unconformity from the overlying Pennsylvanian, and for this reason inequalities of hundreds of feet are not unexpected. The change of the Kinderhook from shale to limestone in passing north and northwest from its outcrops in southern Iowa increases the thickness of the Mississippian above the shales, but here the upper limestones of the Kinderhook can seldom be discriminated from those of higher terranes. Along the eastern part of the belt of outcrop the terrane is naturally thin because of the absence of the superior members.

The thickness of the Mississippian above the Kinderhook amounts to about 300 feet in the southeastern part of the state (Pl. XIV), where it passes beneath the Pennsylvanian rocks, measuring 270 feet at Pella, 300 feet at Newton, 306 feet at

Sigourney, and 320 feet at Dayton. Farther west it apparently thickens, and at Centerville (Pl. XVI) it measures a little more than 500 feet. A like thickening is observed in central and north-central Iowa. At Ames a thickness of 445 feet is assigned to the Osage and the Saint Louis, at Boone (Pl. XI) 485 feet, and at Fort Dodge 500 feet, although at each of these places the base of the Osage is by no means certain. In northwestern Iowa the Mississippian maintains a thickness of more than 200 feet at Cherokee. In southwestern Iowa (Pl. XVIII) it is given 355 feet at Bedford and 280 feet at Glenwood. At Lincoln, Nebraska, it seems to have nearly or quite disappeared.

PENNSYLVANIAN SERIES.

SUBDIVISIONS.

Rocks belonging to the Pennsylvanian series or Coal Measures lie at the surface or immediately beneath the drift in most of southern Iowa and immediately beneath the Cretaceous rocks in western Iowa. (See fig. 6.) The series is divided into two stages, the Missouri and the Des Moines. The Missouri stage (Upper Coal Measures) occupies the southwestern part of the state and consists of shales and limestones. The Des Moines stage (Lower Coal Measures) outcrops to the east of the Missouri stage, and is composed predominantly of shales, with some sandstone and a few beds of limestone. Drill cores and natural sections show in each group a rapid vertical lithologic alternation, and not infrequently the slush bucket brings up from the cutting of the churn drill samples of thin alternating layers of several different kinds of rock. Field exposures show rapid horizontal changes in the strata. Thick lenses of sandstone, for example, thin out in a few miles and are replaced by argillaceous beds.

DES MOINES STAGE.

The Des Moines stage occupies a belt 50 to 80 miles in width, extending from the southern part of Humboldt and Wright counties southeastward to the eastern half of the Missouri state line. An outlier of about 80 square miles overlies the Devonian along Mississippi river in the southern part of Muscatine and Scott counties.

At the base of the Des Moines is a sandstone which though not everywhere present deserves special mention. In the deep wells of eastern Iowa as far west as Des Moines this sandstone is absent from the deeper wells; in southwestern Iowa it occurs in all wells which reach its horizon. At Atlantic it is 50 feet thick, the uppermost half being a gray sandstone of finest grain, succeeded by five feet of sandy limestone, six feet of brown sandstone, and 15 feet of gray sandstone. At Glenwood gray sandstone of imperfectly rounded grains 107 feet thick, including 25 feet of chert and shale, lies immediately upon the cherts of the Mississippian. At Bedford the sandstone attains 160 feet in thickness. (See Pl. XVIII.)

The Des Moines stage in southeastern Iowa consists at the base of shales with some sandstones and singularly persistent thin limestone beds rarely exceeding one or two feet in thickness. These beds are overlain by a series of persistent limestones with shales and coal seams. At the top is the conglomerate, to which Bain applied the name Chariton. On the whole, the well sections of the Des Moines show a large predominance of shales, for the most part gray or blue in color, though heavy beds of dark drab and blackish shales are not uncommon, and red shales occur in many places. In composition they range from pure clay shales to limy, or sandy, or carbonaceous shales, and these may shade off horizontally into limestones, sandstones, or coal.

MISSOURI STAGE.

The upper stage of the Pennsylvanian, known as the Missouri, occupies the southwest corner of Iowa, extending from the middle of the southern boundary to the middle of the western, but the hypothenuse of the triangle thus formed is overlain in the north-central part by a very broken and irregular extension of the Cretaceous. The sediments are chiefly calcareous shales interbedded with heavy and persistent beds of limestone. The latter are remarkably evenly bedded and extend over wide areas. Individual beds of limestone are much thicker than those of the Des Moines stage, in places reaching a thickness of 50 feet or more. About 11 divisions of the Missouri stage have been plausibly discriminated by students in the field, but as no attempt has been made to identify them in the deep-well records they need no detailed mention.

PERMIAN SERIES.

The strata tentatively referred to the Permian occupy so small an area that their effect upon the distribution and quality of underground waters is insignificant. The gypsum deposits in the vicinity of Fort Dodge and the associated red sandstones and shales which have been tentatively referred to the Permian on lithologic and stratigraphic grounds are unfossiliferous. They lie unconformably upon strata of the Des Moines stage, or where these have been removed by erosion, upon the Saint Louis limestone. An erosion interval of considerable length thus separates the period of their deposition from the Des Moines epoch.

CRETACEOUS SYSTEM

DAKOTA AND COLORADO STAGES.

The latest terranes of the country rock of Iowa belong to the Upper Cretaceous. They cover the northwestern part of the state and extend a ragged and broken arm southward almost to the Missouri line in Page county. Over much of the area they occur in more or less isolated patches whose borders can seldom be determined on account of the heavy cover of drift and the infrequent outcrops. On the geologic map of the state the Cretaceous is indicated as a continuous formation over the area embraced by its scattered outcrops.

The Cretaceous rocks of western Iowa belong to the Dakota and Colorado stages. They overlie the Paleozoic formations with pronounced unconformity. The Dakota is a coarse-grained, ferruginous sandstone, very poorly cemented and locally interbedded with seams of clay. In places it includes beds of very fine incoherent sand. It is of the same age as the great aquifer of the South Dakota artesian slope, but being separated from that area by outcrops of the Sioux quartzite it does not show the high artesian pressure which characterizes the formation in the South Dakota field.

Overlying the Dakota sandstone occur shales and calcareous beds of the Colorado stage. Drillers in western Iowa should take special pains to discriminate these from the pebbly clays of the drifts.

TERTIARY SYSTEM

In a few localities patches of gravel and sand discovered beneath the drift have been tentatively referred to the Tertiary system.

In Tertiary and other preglacial periods the long disintegration and decay of the country rock produced a deep mantle of residual material, which was not wholly swept away by the invasions of the Pleistocene ice sheets. Over the driftless area residual clays remain continuous and heavy. Elsewhere they have been largely removed by glacial erosion and are now found in thin and scattered patches occupying depressions in the rock surface underneath the drift. Formed of the insoluble constituents of the country rock, they spread over the limestone and shale areas of the state as stiff, plastic, and impervious clays colored deep red or brown by iron oxides. Where cherts are present in the parent rock their insoluble fragments may form a large part of the deposit.

Decay and disintegration, no doubt in large part preglacial, have affected the country rock in another way which directly concerns the distribution of ground water. Sandstones have been broken down into beds of incoherent sand by the removal of their cements, and heavily bedded limestones have disintegrated into a surface zone of thin spalls by the detachment and fracture of their constituent laminæ. Thus has been opened up beneath impervious residual clays and till sheets a zone of ready passage for ground water.

QUATERNARY SYSTEM

PLEISTOCENE SERIES.

The Pleistocene series in Iowa comprises the deposits of five distinct glacial stages and of four interglacial stages. The deposits of the glacial invasions consist of stony clays—the ground moraines of ancient ice sheets—together with beds of sand and gravel sorted and laid by the waters of the melting ice. The stratified and unstratified deposits together constitute the drift. The deposits of the interglacial epochs include old soils, marsh, and forest beds, and sands and gravels laid by the rivers of the time. (See Pl. III, in pocket.)

NEBRASKAN DRIFT.

The oldest and lowest glacial deposit is that of the Nebraskan stage. It embraces both sands and gravels laid down on rock by streams deploying in front of the advancing glacial ice, and also a ground moraine of blackish till bearing a large number of greenstone pebbles.

AFTONIAN GRAVEL.

The Aftonian interglacial epoch derives its name from Afton Junction, Union county, Iowa, where heavy deposits of sands and gravels were found lying between the Nebraskan drift and that of the succeeding glacial stage—the Kansan. These type deposits were at first supposed to have been laid down by floods of the melting ice of the Nebraskan glaciers, but the recent discovery at a number of localities in western Iowa of Aftonian gravels carrying a rich mammalian fauna proves that they were laid down during an interglacial time whose climate was far from boreal.[1]

On the uplands these gravels are generally thin and in places are entirely wanting; in the lowlands they form extensive beds, in many places filling the preglacial valleys to depths of 50 to 60 feet. To the same stage belong old soils and forest beds developed on the Nebraskan drift sheet. In the southwestern part of the state these layers bear decaying organic matter known by drillers as "sea mud," "stinking clay," and "black muck," which not infrequently renders the waters of deep-bored wells obnoxious.

KANSAN DRIFT.

The deposits of the second ice invasion consist largely of a clayey till, dense, tough, and difficult to excavate, charged with many small pebbles and sparse bowlders. Little stratified ma-

[1]Calvin, Samuel, Bull. Geol. Soc. America, vol. 20, pp. 341-356.

terial is intermingled or associated with the Kansan drift. The till is blue-drab in color where unweathered, but so great is its antiquity that it is reddened by oxidation to a considerable depth. The Kansan drift was spread over all the state outside of the driftless area, and to it belongs the larger part of the stony clays pierced by the drill in any county.

YARMOUTH STAGE.

In eastern Iowa, where the Illinoian drift sheet overlaps the Kansan, there are found old soils and weathered surfaces belonging to the interglacial stage called the Yarmouth, from the village of that name in Des Moines county. The gravel that is widely spread over the Kansan drift in Buchanan and other counties of northeastern Iowa overrun by the Iowan ice and hence termed the Buchanan gravel, was probably laid down in Yarmouth time. Two phases are discriminated by the Iowa State Survey—an upland phase, heavily rusted and decayed, and a valley phase of sands and gravels more quartzose in character.

ILLINOIAN DRIFT.

Within the narrow belt of its occurrence along Mississippi river in southeastern Iowa the Illinoian drift consists mainly of a clayey till differing from the Kansan till in the larger proportion of dolomite pebbles which it carries, in a slightly less compact structure, and in a weathered zone of lesser depth. The upper surface of the drift sheet underneath its cover of loess is marked by a leached gray soil and vegetal deposits of the Sangamon interglacial stage.

IOWAN DRIFT.

The Iowan drift, as discriminated by Calvin, is recognized most readily by the characteristic topography already described (p. 56). It is exceptionally thin. It consists of a light yellow clayey till and numerous large superficial bowlders, generally of granite.

WISCONSIN DRIFT.

The latest ice invasion of the state laid down a ground moraine of clayey till containing a notably large proportion of limestone pebbles. The slight extent to which it has been oxidized and leached of lime marks its recency. The drainage of Wisconsin time was exceptionally vigorous. Gravel hills called kames mark the places where glacial streams reached the margin of the ice and threw down their loads. Outwash sands and gravels cover whole townships in continuous sheets, and deep gravel deposits were laid down by swollen rivers along all waterways leading outward from the area of this drift.

LOESS.

Loess is a gritless loam intermediate in size of particles between sand and clay. Because of its loose texture it is highly permeable. Much of the surface yellow loess is underlain by a blue-gray loess supposed by some to be of greater age. In other places it may graduate into a reddish loam intermediate in texture and color between loess and the red residual clays or the red weathered clays of the drift on which it rests.[1]

About the Iowan border and also over wide areas of the Illinoian drift the loess passes downward into sand by interbedded alternate layers of the two deposits. Such deposits are sometimes referred to as subloessial sands. Loess is widely distributed in Iowa, covering practically all the state except the areas of the Iowan and the Wisconsin drift sheets, and being found even upon these in some small patches.

ALLUVIUM.

Alluvial deposits consisting of many feet of sand and gravel alternating with clay and covered with silt and loam fill the valleys of most of the larger streams to a considerable depth. Much of this material belongs to deposits already described, but is indistinguishable from the more recent beds.

[1]Norton, W. H., Geology of Scott County; Iowa Geol. Survey, vol. 9, pp. 486-487.

CHAPTER III.

GEOLOGIC OCCURRENCE OF UNDERGROUND WATER.

BY W. H. NORTON, HOWARD E. SIMPSON, AND W. S. HENDRIXSON.

CLASSIFICATION OF UNDERGROUND WATERS

In a prairie region of uniform and abundant rainfall, such as prevails throughout Iowa, the permanent ground-water level may be found at no considerable distance below the surface, and water suitable both in quality and quantity for domestic, farm, and village supplies may generally be obtained from shallow wells. Many such shallow waters are too meager or too liable to pollution to meet the needs of industrial plants and of towns and cities. Where large supplies of the purest ground water are needed it has been necessary to resort to artesian waters of the deeper zones of flow reached by wells hundreds and in some places thousands of feet in depth.

The underground waters of Iowa, therefore, fall into two groups. The first group, comprising those available for home, farm, or village supply, commonly lie less than 100 feet and rarely more than 500 feet below the surface, and are usually obtained from bored, driven, or drilled wells, or in a few districts where the valleys are cut beneath the ground-water table, directly from springs. These waters are frequently termed shallow or local waters, as they are fed directly by local rainfall absorbed through the soils above. Wells drawing their supply from these sources penetrate only the drift or superficial deposits and the country rock—the rock terrane outcropping in the area or immediately underlying the superficial deposits.

The second group of waters, those belonging to rock strata buried below the country rock and circulating through the more permeable layers under greater or less pressure, are termed artesian waters, and wells deriving their supply from such waters are termed artesian wells whether they flow at the surface or not. Many cities and industrial plants resort to these waters, while others utilize groups of shallow wells in alluvial deposits or the surface waters of streams.

The line of separation between the country-rock waters and the artesian waters can not, however, be sharply drawn. In the driftless area in northeastern Iowa the deep artesian rock systems rise and become country rock, and practically all the common wells are of the artesian class, though few exceed 500 feet in depth. Artesian wells are also found in both the drift and the country rock immediately under the drift, many of them at depths much less than 500 feet. And again in some portions of the state ordinary wells pass through the shallow drift and country rock into formations not exposed near the surface.

WATERS OF THE ROCK FORMATIONS

ARTESIAN FIELD.

OCCURRENCE OF WATER.

The artesian field of Iowa is but a part of an extensive area of the upper Mississippi valley where artesian conditions prevail—an area embracing southern Wisconsin and Minnesota, northern Missouri, and a large part of Illinois. The chief water beds, or aquifers, of the artesian system of this large area outcrop in southern Wisconsin and Minnesota, so that these states include the gathering ground from which the artesian waters are collected. On account of the very gentle inclination of the strata and the thickness of the chief aquifers, the collecting area is exceptionally large, and this, together with the abundant rainfall of the region, insures the artesian field, as a whole, against exhaustion.

From the intake area, or area of outcrop, the strata of the artesian system have a general southward inclination. They do not, however, show a uniform artesian "slope," but lie in the form of a shallow trough open to the southwest. The axis of the trough enters the state from the north about midway between the eastern and western borders and leaves it at the southwest corner. In southeastern Iowa the lower beds of the Paleozoic rise in a dome now covered and concealed by later Paleozoic formations. It is possible also that in southern Iowa begins the upward rise of the lower Paleozoic strata disclosed in deep wells in north-central Missouri. As the strata of southeastern Nebraska dip also toward the axis of the trough, the Iowa field is somewhat spatulate, and needs only to be closed by a rise of strata to the southwest in order to form an artesian basin.

So gentle is the inclination of the strata that the Cambrian and Ordovician water beds remain within reach of the drill and may be profitably exploited over all except the southwestern part of the state, where the dip of the trough carries them so deep that so far no well has reached them. Here, however, higher water horizons of the same system are able in part to take their place.

The map (Pl. I, in pocket) showing the distribution of artesian wells in Iowa roughly indicates the nearness of the chief aquifers to the surface. Thus, in eastern and northern Iowa, where wells are numerous, the depth to the aquifers is slight, and toward the southwest, where they are fewer, the distance to the water beds is steadily increasing.

The Cambrian and Ordovician systems contain a number of thick water-bearing sandstones which supply the deep wells in the northeastern part of the state. These are, in downward succession, the Saint Peter, New Richmond, Jordan, Dresbach, and the older Cambrian sandstones. The Paleozoic formations above the Saint Peter also contain water-bearing members, chiefly limestones and sandstones, but these can scarcely be compared with the sandstones already mentioned for the quality and quantity of their water.

The Cretaceous system contains considerable water in the Dakota sandstone, which is its basal formation, and supplies many wells in the western part of the state.

The Pleistocene deposits, especially the beds of sand and gravel, yield supplies to innumerable shallow wells in nearly all sections and are the most important source of water in the state.

QUALITY OF WATER AS RELATED TO GEOLOGIC SOURCE.

To determine with accuracy the quality of water supplied by the different geologic formations seems well-nigh impossible from the data at hand. This is due to several facts:

In very few, if any, deep wells are the waters known to be derived from a single stratum. Many wells from 1,000 to 2,000 feet deep are cased only to rock. Some are cased for a few hundred feet; few are cased more than 1,000 feet; scarcely a single very deep well is cased to the lowest water-bearing formation. It is evident that the output of most of the deep wells, therefore, represents a mixture of all flows below the casing. This is true, for example, of the wells at Cedar Rapids, cased to 85 feet; of the well at Hampton, cased to 200 feet; of the well of the Murray Iron Works at Burlington, whose water, according to the owner, represents all flows; and the same may be said of many others.

Casings in many Iowa deep wells are short-lived. The casings of well No. 1 at Grinnell, of No. 2 at Centerville, and of the wells at Cedar Rapids illustrate the destructive action of the upper waters on iron tubing. It seems probable that the life of such casing when exposed to the action of the heavily mineralized waters of the Carboniferous may be only 5 to 10 years, and therefore waters shut out when the well is drilled may later enter the well.

Casings are often faultily put down and do not shut out the waters they were intended to exclude. Though the wells at Grinnell have been cased with as much care as others, they are good illustrations of faulty casing. In well No. 1 there was known to be a break in the casing at about 400 feet, and the well always yielded water containing about 2,000 parts per million of solids. The water had the characteristics of the water from several shallower wells in the neighborhood, which are known to derive their waters from the drift just above solid rock and from the Carboniferous. Well No. 2 was provided with a continuous casing for about 840 feet, and while the casing remained in good condition its water contained less than half as much mineral matter as well No. 1, the best analysis showing 881 parts total solids, though even then a small flow of very hard water surely entered at about 1,530 feet. Several years after it was drilled it was found that the shale had caved, filling the well to 1,700 feet, or just above the Saint Peter sandstone, and an analysis at the time, mainly of the flow at 1,530 feet showed about 5,000 parts of solids. Though several analyses have been made of water from well No. 3, which was drilled and cased to the same depth as well No. 2, none of them have been as low in solids as the 881 parts found in No. 2, the lowest for No. 3 being 1,147 parts. It is probable that the casing of this well is not perfect as far as it goes, and it is certain that none of these wells have yielded water from only the Saint Peter and the New Richmond sandstones.

The water in one stratum may find access to another through fissures or more slowly by seepage. The similarity of the waters from the sandstone strata of the Cambrian and the Ordovician gives some support to this view.

Though the stratum supplying the greater part of the water can be determined in many wells, the entrance of a small amount of water from another stratum may render such information valueless in a region like Iowa, where many waters are so highly mineralized. For instance, 90 per cent of a well's yield might come from a formation supplying excellent water, but the other 10 per cent, coming from a formation furnishing salt water, might render the supply nonpotable.

Though the characteristics of the waters from the several aquifers cannot be made out with scientific accuracy in all parts of the state, much may be learned of these waters from the data at hand, and there is little doubt as to their quality in general.

WATER IN PRECAMBRIAN ROCKS.

SIOUX QUARTZITE.

The close joints which appear in the Sioux quartzite at its outcrops and some little-indurated sandy layers which it includes permit it to contain a considerable quantity of ground water. These joints, however, may be expected to decrease rapidly with increase in depth. It should be clearly understood, then, that the drilling of deep wells below the summit of the pre-Cambrian of Iowa is not only difficult and costly, but also futile. In no place within the limits of the state can it be encouraged. When the drill reaches these crystalline rocks the work should cease. But the question whether the pre-Cambrian rocks have really been reached can not be left to either the workman or to the citizen untrained in the determination of rocks. It must be decided by an experienced geologist.

The Sioux quartzite is known to yield small quantities of water,[1] and at Sioux City about three gallons a minute is reported to be obtained from schist at a depth of 1,480 feet, but it is needless to say that such small supplies do not repay deep drilling through hard rocks.

WATER IN CAMBRIAN AND ORDOVICIAN ROCKS.

CAMBRIAN SYSTEM.

DRESBACH SANDSTONE AND UNDERLYING CAMBRIAN SANDSTONES.

Wells.—The porous saccharoidal Dresbach and underlying Cambrian sandstones yield freely an excellent water in northeastern and eastern Iowa. It is these sandstones which supply the many flowing wells of the valley of Upper Iowa river and furnish a large part of the flows of the deeper wells of the immediate valley of the Mississippi as far south as Davenport. West of the Mississippi it has seldom been necessary to drill to these horizons. No water was reported in these sandstones at Cedar Rapids and Anamosa, although this fact does not make it certain that none was found. At Boone these sandstones supply the major portion of the flow. With increasing depth to the west and southwest they become less and less pervious as their pore spaces are increasingly filled with cements, and the water which they contain becomes more and more highly mineralized.

Springs.—These sandstones outcrop so slightly as to produce few springs. The high artesian pressure, however, supplies water for a goodly number which flow from joints in the overlying Saint Lawrence formation.

WATER IN THE SAINT LAWRENCE FORMATION.

The shales and, as a rule, the calcareous beds of the Saint Lawrence formation are dry. At Waterloo, however, the latter

[1]Hall, C. W., and others, Geology and water resources of southern Minnesota; Water-Supply Paper U. S. Geol. Survey No. 256, 1911, pp. 48, 56.

are said to yield water. In general, the impermeable beds of this terrane serve to separate the water of the Dresbach and underlying sandstones from that of the Jordan sandstone, allowing each to maintain its individual characteristics.

As stated above, many springs originating in the Dresbach and underlying sandstones find exit through the shales of the Saint Lawrence formation.

WATER IN THE JORDAN SANDSTONE.

Wells.—The Jordan sandstone is one of the chief, if not the chief, of the aquifers of the Iowa artesian system. It is reported as a water bed at Dubuque, Clinton, Davenport, Waverly, Waterloo, Vinton, West Liberty, Ames, and Ottumwa. It no doubt furnishes large yields in many other wells whose water horizons are not recorded. The rather coarse, smooth, well-rounded uncemented grains of quartz afford large pore spaces which permit the ready percolation of artesian water, and the absence of soluble constituents leaves the water with comparatively low mineral content. At few places have any accurate tests been made of the capacity of the Jordan as compared with that of other water beds. At Ames the ability of the Jordan to contribute to the general supply was found to be nearly four times that of the New Richmond and fifteen times that of the Saint Peter.[1]

In the valleys of the main rivers and their tributaries where the Jordan outcrops it supplies many ordinary wells, some of which give constant flows, but the head is not strong because of the leakage through the many outcrops along the valley walls. The formation is tapped by many upland wells in the northern and eastern portion of Allamakee county, but the head is so low that the wells are commonly continued down into the Dresbach or underlying sandstones, where no better water is found but where a stronger head is obtained, owing to the presence of the overlying shaly limestones of the Saint Lawrence formation, which prevent the upward dispersal of its artesian waters, and the very small area of outcrop from which leakage in the form of springs may occur. Farther from the numerous outcrops the head of the Jordan rises, and many wells in the northeastern

[1]Beyer, S. W., Iowa Agricultural College water supply, 1897, p. 11.

portions of Winneshiek and Clayton counties pass through the Oneota limestone to procure the excellent water of the Jordan.

Springs.—Springs are very numerous in the Jordan sandstone owing to the large pore space between its grains and the lack of interstitial filling. Many flow freely from the rock where it overlies the limestone of the Saint Lawrence formation and from above the scattered shaly or limy bands.

Wherever the Jordan outcrops on the valley walls its waters drain away freely in seeps and springs, and wherever its contact with the underlying shaly limestones of the Saint Lawrence is exposed the water collected over this impervious floor flows out, frequently in powerful streams.

WATER IN THE ORDOVICIAN SYSTEM.

PRAIRIE DU CHIEN STAGE.

Wells.—The Prairie du Chien stage is one of the most important of the aquifers of Iowa. Underground waters have no doubt opened passages along joint and bedding planes through their solvent action on the limestone. The sandy intercalated layers, although neither thick nor persistent, offer easy paths for ground water, and communicating as they must with the channels of solution, form water beds which the drill seldom fails to tap. The New Richmond sandstone especially is a water carrier and adds materially to the supply at Dubuque, Waterloo, Vinton, Grinnell, West Liberty, Ames, and Des Moines. A still larger number of wells find water in the lower limestone, the Oneota dolomite, these being so far as reported, the deep wells at Waterloo, Clinton, Sumner, Anamosa, Cedar Rapids, Homestead, West Liberty, Ottumwa, Des Moines, and Centerville. A few wells, such as those at Waverly, Waterloo, and Grinnell, are reported to obtain water from the Shakopee dolomite, and as this formation has many sandy layers the number of wells which receive accessions to their supply from this source is probably larger than the records show.

The Prairie du Chien in many places seems to offer no impervious floor to the Saint Peter, and there appears no reason why the waters of the two should not in general freely mingle; some wells, however, have found shaly beds which lie between the two terranes and locally keep their waters separate.

Springs.—Owing to its many open joints and bedding planes and even large solution caverns, the Oneota produces many large springs. The strongest of these are near the base, where its openings permit the escape of artesian water from the Jordan sandstone. From this horizon flow many of the powerful springs of the Mississippi and Oneota valleys in Allamakee county.

The New Richmond sandstone gives rise to many small flows and much seepage along its contact with the underlying Oneota.

WATER IN THE SAINT PETER SANDSTONE.

Wells.—The Saint Peter is easily distinguished by drillers and is perhaps the best known of Iowa's geologic formations. It never fails to yield some water and in many places yields abundantly. The head of the water differs from that in overlying terranes, so that the inflow of water into the tube at this horizon is readily marked, whereas lower flows, with about the same head as that of the Saint Peter, may either escape the observation of the driller or be thought not worthy of record. The list of wells which are reported as drawing water from the Saint Peter is too long for mention, including as it does a large number of the deep wells of the state.

The pore spaces of the Saint Peter are large, owing to its "millet-seed" structure, and the moderately large, well-rounded grains, fairly uniform in size, do not pack so closely as do sandstone grains more diverse in size and in shape. The pore spaces are unfilled. No clay was laid down along with the quartz grains on the ancient sea floor. Since the uplift of the formation ground water has seeped freely through it, and, if interstitial deposits were ever made by mechanical or chemical processes, they have long been dissolved and washed away. The smoothness of the grains brings the friction of water in transmission to a minimum. For all these reasons the capacity of the Saint Peter for storage and transmission of water must equal that of a bed of ordinary incoherent sand.

On account of the well-nigh complete absence of soluble materials in both the constituent grains and the interstitial cements of the Saint Peter, the water seeping through it has little opportunity to take minerals into solution, and it therefore remains of exceptional purity for long distances from its sources.

The Saint Peter is within reach of farm wells in all of Clayton county, the southern and western portions of Allamakee county, the northern and eastern portions of Winneshiek county, and the eastern portion of Dubuque county. (See Pl. I, in pocket.) Throughout this area one of its striking characteristics is its low head in comparison with overlying terranes, especially near the area of outcrop. Wells sunk through overlying strata with a high head of little water immediately lose 100 or 200 feet of this head on penetrating the Saint Peter but find at the same time an abundance of water. The reason may be found in the freedom with which water flows through this very permeable rock both to outcrop and to well holes giving a constant supply but little pressure; whereas in the overlying rocks with small storage and transmission capacity the pressure is relieved and the water is drawn away immediately on pumping.

Springs.—The massiveness and the lack of stratification planes and crevices are not favorable to the gathering of the abundant water of the Saint Peter into definite channels and its discharge in copious springs. Nevertheless small springs from it are common and seepage universal, and it is an important contributor to the flow of all streams over its area of outcrop.

WATER IN THE PLATTEVILLE LIMESTONE AND DECORAH SHALE.

The shale of the Platteville limestone and the Decorah shale yield no water and in many borings must be cased to prevent caving. They serve an important office in maintaining the head of the waters of the Saint Peter sandstone, whose upward leakage they prevent, and also in separating them from the waters of the Galena dolomite.

WATER IN THE GALENA DOLOMITE.

Wells.—Sealed between two shales, either the Decorah shale or the shales of the Platteville limestone below and the Maquoketa shale above, the Galena forms a water bed of no little value. Where dolomitized and nonargillaceous, it is porous, not indeed sufficiently to permit free percolation but enough to give rise to incipient waterways along joints, bedding planes, and specially porous layers, and these have developed by solution into definite channels capable of a large yield to wells.

Though no assurance can be given that the drill will strike one of these channels, it has done so in a good many of the Iowa wells, as at Clinton, Davenport, Fort Madison, Sumner, Osage, Mason City, Hampton, Webster City, Holstein, Grinnell and Pella. At Davenport the Galena water is so nearly identical with that of the Saint Peter in quality and head that a rise of the latter through the crevices of the Galena is strongly suggested. The yield from the Galena and Platteville is in some places abundant, amounting in some of the wells in Davenport and Rock Island to 300 or 400 gallons a minute. At Mason City the entire city supply is drawn from these formations.

In shallow wells the Galena affords excellent water throughout its area of outcrop. Its base at least is saturated, and southward and westward, where it dips under the Maquoketa shale, it continues water-logged. Thus it remains the chief source of farm wells in large areas of Winneshiek, Clayton and Dubuque counties, where wells penetrate the Maquoketa shale and are drilled to depths of 300 to 400 feet to reach it. The waters are hard, from limestone dissolved in passage, and may be in places contaminated by surface drainage, through the numerous sink holes opening into fissures which everywhere traverse the rock. The freedom of circulation and the potency of the Galena waters to carry materials in solution for long distances is shown in the deposits of lead and zinc ores which are found in abundance in the old crevices, fissures, and caverns of the Galena about Dubuque. In West Dubuque there is an area so cut up by labyrinthine passages underground and so full of water that it is known as the McPoland Pond. On one occasion a small skiff was taken down a shaft and used in exploring this ground.

Springs.—The springs issuing from the Galena dolomite are among the most copious in the state. This is a direct result of the many channels, some cavernous in size, that have been opened by solution along bedding planes and intersecting joints. The chief horizon is that at the base of the formation, immediately above the impervious Decorah shale. Over the wide areas where the Galena is the country rock, large numbers of sink holes pit the surface and lead the storm waters directly into the fissures and thus furnish a ready supply of water. In some places storm waters are led so directly to a near-by valley that they form a large part of the supply of some spring, which readily responds to every rainfall by showing a proportional increase in volume and turbidity. Such springs, however, should be avoided, as they are very liable to polution by organic impurities washed into the sink holes with the water.

WATER IN THE MAQUOKETA SHALE.

Wells.—The thick impervious clay shale known as the Maquoketa shale not only prevents the rise of Cambrian and Ordovician artesian waters into higher terranes but also forms an impermeable floor for the Niagaran waters above it. In this respect it is of especial value over the large area of Niagaran outcrop in eastern Iowa, where, by preventing the downward leakage, it causes the water of the Niagaran to accumulate sufficiently for the supply of small towns and villages. The dolomites of the Middle Maquoketa, which occur in a few counties of northeastern Iowa, are water bearing, as was found in the deep wells at Sumner and Green Island.

Springs.—Although springs from the contact of the Maquoketa and the overlying Niagaran derive their water from the latter, their value inures almost entirely to the Maquoketa areas. They are of greatest importance in Clayton, Dubuque and Jackson counties, where they supply many perennial streams with water, such, for instance, as Little Maquoketa river, which never ceases to bear its contribution to the Mississippi just north of Dubuque, whereas its neighbor, Catfish creek, which parallels it immediately to the south but is not spring fed, responds to every drought. Two miles north of Strawberry Point a mill is operated by a turbine wheel run by a strong stream piped from a spring of this horizon to the wheel pit.

SPRINGS FROM CAMBRIAN AND ORDOVICIAN ROCKS.

The area over which Cambrian and Ordovician strata form the country rock is especially noted for its springs. No other part of Iowa is so well supplied, and perhaps in all the other provinces of the state taken together there will not be found so large a number of strong streams of pure water flowing from the bedrock as are found here. The conditions which are so favorable to spring formation in this area are these: (1) Several heavy, porous beds of sandstone and creviced limestone with large capacity for both storage and transmission of water; (2) beds of impervious clay and shale which check the downward movement of the ground water, causing it to collect in large quantities; (3) many deeply carved valleys and innumerable ravines, the bottoms of which are well below ground-water level; (4) a slight dip, which facilitates the movement of the water along the surface of the impervious layers to the outcrops on the sides of the valleys; since this dip is to the southwest, springs are commonly found on the north and east sides of the valleys; (5) an ample rainfall (over 30 inches annually); and (6) the exposure of the porous beds over a relatively flat surface unsealed by drift, thus permitting them to absorb the rainfall.

The chief spring horizons in the Cambrian and Ordovician, named from oldest to youngest, are the contacts of the Dresbach and Saint Lawrence, the Saint Lawrence and Jordan, the Jordan and Oneota, the Oneota and New Richmond, the Shakopee and Saint Peter, the Decorah and Galena, and the Niagaran and Maquoketa. All except the first and third are contacts between heavy porous sands or creviced limestone and underlying impervious shales. The two exceptions, the Dresbach-Saint Lawrence and the Jordan-Oneota contacts, occur at the base of heavy limestones that overlie sandstone aquifers, the waters of which are under artesian pressure, the lower beds not outcropping. The open joints of the limestone connect with the porous sandstone over large areas and admit the waters from below, and they flow out through crevices in copious and at times even powerful streams. Owing to the fact that many of the springs emerge through talus and washed soil at the foot of the bluffs and on the valley sides, it may be impossible to determine the formation from which they come. Again, many springs, some very strong, come from local beds lying above shaly layers in the heavy aquifers. Many are, however, readily identified.

The economic value of these springs to the residents of the fertile valleys of northeastern Iowa can hardly be estimated. The water power of the many small springs which in many places issue a hundred feet above the base of the bluffs and fall in cascades has been but slightly utilized. Here and there, however, a mill is operated, and at some of the many farmhouses whose location has been determined by the presence of a spring the stream is so piped as to generate power for separating the cream, churning the butter, and driving small labor-saving machinery about the farm. In a few places, too, a portion of the power of the flowing water is utilized in a ram to drive another portion into a system of waterworks for home and farm. The possibilities in these lines have as yet been but slightly developed, but even in its simplest use, where the pure, clear, cold stream flows through the tanks of the spring house, giving the most wholesome kind of water for home use, passes through the simple refrigerator, cooling the milk and preserving the butter, and then flows through the barnyards and pasture, supplying the stock with water that is cool in summer and warm in winter, its value in health and comfort is difficult to estimate in dollars and cents.

Because of the large number and the great size of the springs of the area of outcrop of the Cambrian and Ordovician rocks in the northeastern counties of the state, the streams of this area are exceptional in the constancy of their flow and the purity of their waters.

QUALITY OF THE CAMBRIAN AND ORDOVICIAN WATERS.

The four great sandstone layers of the Cambrian and Ordovician may be discussed together, since there is generally no essential difference in the quality of their waters. These layers are the water bearers for all the deeper wells in the northeast part of the state within the area of good water, so often mentioned, extending south and west to about the line of the Mississippian. With the exception of the very deep park well at McGregor all deep-well waters within this area have low solids, rarely exceeding 500 parts and averaging about 400 parts per million. In this part of the state there are no formations later than the

Devonian, and in a considerable portion of it rocks of the Cambrian and the Ordovician underlie the drift. Except perhaps in the drift there are no objectionable waters to be cased out or to contaminate the waters in the sandstones below.

Some examples may be given to illustrate the fact that the waters are about the same whether from the Saint Peter or from lower strata.

On page 168 are given analyses of seven deep waters in Allamakee county, six of which are supposed to be derived from the Dresbach or underlying Cambrian sandstones, and one at Postville from the Saint Peter. The six have about the same total solids and their average solids are about the same as those of the water from the Postville well. In Clayton county the 1,006-foot well at McGregor is exceptionally deep and reaches salt water. A much shallower well at the same place also shows the influence of the salt. Six other wells in Clayton county (p. 169) show about the same amount of solids, though their depths are greatly different, and their footings are believed to range from the Dresbach or underlying Cambrian sandstones to the Galena. In Cerro Gordo county six analyses of well waters show about the same total solids, though two of the wells are supposed to draw from the Saint Peter, three from the Galena, and one from the Devonian (p. 172). The wells are cased only to rock. No inference can safely be drawn from the analyses of water from the 1,473-foot well as to the character of the water below the Saint Peter at this point, as it is doubtful whether the sample of water was collected while the well was in active use. The analysis of water from the well at Hampton shows that the softness of the waters from the lower sandstones is preserved as far south and west as Franklin county. This well is cased only 200 feet, foots in the Jordan, and may draw water from all strata from the Jordan to the Mississippian.

The water of the Saint Peter is soft as far west as Emmetsburg, for the well at that place owned by the Chicago, Milwaukee & St. Paul Railway foots in the Saint Peter and gives excellent water. In the same county two shallower wells in the Dakota sandstone give hard water. The low solids in the well at Emmetsburg may be ascribed to the successful casing out of a strong flow of hard water from the Dakota sandstone which probably finds access to the deep well at Mallard, also footing in the Saint Peter. Successful casing to preserve from contamination the waters of the Saint Peter or lower strata has not been accomplished so far as known in wells located where the surface rock is later than the Mississippian. Owing to the similarity of the waters of the lower sandstones one might be inclined to infer that the waters of these strata mingle, and this may be true. Numerous wells, however, reaching higher levels show, as at Grinnell and Emmetsburg, that strata not far removed from one another in geologic succession may contain very different waters.

WATER IN THE SILURIAN SYSTEM.

NIAGARAN DOLOMITE.

Wells.—The Niagaran dolomite, like the Galena dolomite, is traversed by irregular channels of solution through which water flows with considerable freedom, and includes porous beds through which it seeps with some difficulty. The ground water which the formation receives over its outcrop area is held within it by the impervious Maquoketa shale beneath and passing down the dip acquires artesian pressure and feeds wells as far distant as Burlington, Keokuk, Centerville and Des Moines.

The Silurian sandstones in southeastern Iowa largely increase its water resources, and these are drawn upon freely at Washington, at Centerville and probably at Ottumwa.

Throughout its area the Niagaran is the almost exclusive source of supply for shallow rock wells, as it ranges from 200 to 400 feet in thickness and overlies the Maquoketa, a bed of impervious shale whose thickness is more than 100 feet. To the south and west, where the Devonian is the country rock, the Niagaran is the source of many wells, for the overlying Devonian limestones feather out eastward.

The Niagaran transmits water very freely, not only through many small cavities, but especially through a large number of joints, cracks, bedding planes, and open crevices formed by solution in the soluble rock, through which an active circulation obtains. In number and size, however, the open cavities are small compared with those of the Galena.

The water absorbed over the large intake area of this formation is held by the impervious shale beneath from passing downward, so that at least the base of the limestone is water-logged and the contact with the shale forms a strong well and spring horizon.

The margin along the bold eastern escarpment is so well drained that in many places it is difficult to secure good wells. Farther back the ground-water level rises until along the margin of the overlying Devonian the formation is almost entirely saturated and wells obtain an abundance of water soon after penetrating it. Though rarely dry at the base, it is subject to the disadvantage common to other limestones—the possibility that the drill may go a long distance, even through the formation to the shale, without striking one of the crevices or water passages. Perhaps the most constant water-bearing bed of the formation is an especially porous, granular stratum lying some distance above the base.

The Niagaran is commonly saturated immediately below the drift and it is from this part of the formation that many of the large farm-stock wells of its country-rock area draw their supply. The upper portion of the rock is very generally broken and shattered by the glacial ice and the fragments are mingled with the old residual soil and with gravels deposited by waters flowing out in front of the advancing ice. The whole makes a good waterway and a remarkably strong source for wells. The water is perhaps more truly that of the drift than that of the rock, but all drilled wells which draw from it should have casings driven into the rock and should draw from the many crevices therein.

The water from the Niagaran is usually copious enough for the public supply of towns of 1,000 or 2,000 population or for minor industrial purposes, though in some places it may be unsatisfactory as a boiler water on account of its hardness. Unless it is desired to seek the deep artesian supplies it is not advisable to attempt to drill below the base of the Niagaran, as the Maquoketa shale is dry. If the shale is reached without the drill having found a water crevice and it is decided not to penetrate the artesian aquifers an attempt may be made to open the drill hole to a water-bearing crevice by torpedoing the well with nitroglycerin. This, however, should be done only after it is fully decided to abandon the hole if water is not found in this way, as drilling can not be resumed after the shooting. The drill hole should be filled up to the base of the Niagaran, and the shot fired on top of this filling. If this course fails it will be necessary to try a new hole.

Springs.—Springs are very numerous along the base of the Niagaran escarpment and in the heads of the narrow ravines which deeply notch it all the way from the headwaters of Turkey river in Winneshiek county along the bluffs overlooking Volga river and those facing the Mississippi river as far south as Clinton. Owing to the numerous thin shaly layers interbedded with the limestone, springs are abundant well up within the formation. Many are found in Delaware county along Maquoketa river and all its tributaries, which have cut their channels well into the limestone. Among the most notable are the group about the "Backbone," in Richland township, and the many that supply Spring creek, in Delaware and Milo townships. The purity and abundance of the waters poured into Spring creek are attested by the location here of a large Government fish hatchery controlled by the United States Bureau of Fisheries.

QUALITY OF SILURIAN WATERS.

A number of wells of very moderate depth foot in the Silurian where it is overlain only by the drift or by the Devonian and the drift. Examples are wells at Covington, Mount Vernon and Lisbon, in Linn county; Morley and Onslow, in Jones county, and Grand Mound, in Clinton county. All except the Covington well have lightly mineralized waters, and that well contains only about 700 parts per million. All other wells footing in the Silurian are deep, such as Mrs. Huber's at Tama and the city wells at Farmington, Centerville, and Bedford. They penetrate water-bearing strata above the Silurian, which are probably not cased out, and their waters can give little indication as to the real character of the Silurian water at those places.

WATER IN THE SALINA (?) FORMATION.

The Silurian beds which are tentatively regarded as representing the Salina formation are, wherever found, distinctly deleterious to underground waters owing to their content of lime-sulphate minerals. The presence of sulphate in the form of anhydrite indicates that it has been hermetically sealed from all underground waters since its deposition and can increase their mineralization only when new channels are opened by the drill. But the high content of lime sulphate in deep-well waters when these strata are penetrated indicates that much of the gypsum lies in the path of artesian waters. The analyses of the water of the deep city well at Pella show that it contains 4,678 parts per million of SO_4 and 444 parts per million of calcium and is entirely unfitted for municipal supply. At Nevada the very heavily sulphated water suggests that the Silurian here, as at Marshalltown, twenty-eight miles east, is gypsiferous, although this can not be proved as no samples were preserved. At Mount Pleasant any seleniferous waters from the well-marked gypsum beds were successfully cased out from the later wells drilled at the State Hospital for the Insane. At Grinnell the first well drilled for the city showed an abnormally high lime-sulphate content, but with better casing the quality of the waters of the later wells was very much improved. At Glenwood the water veins occur above the gypseous beds, which are apparently dry, as the water contains little calcium sulphate. At Bedford the waters from the supposed Salina horizon showed an enormous increase in lime sulphate and were pronounced unfit for city supply. The presence of these strata in southern Iowa constitutes a distinct discouragement to artesian drilling in that part of the state, though otherwise the Silurian might prove valuable, for it is much more accessible than the Cambrian and Ordovician beds.

WATER IN THE DEVONIAN SYSTEM.

ARTESIAN CONDITIONS.

Wells.—The Devonian rocks can not be classed among the important water beds of Iowa, although they contribute somewhat to the general deep-well supply in several places, as at Vinton, Cedar Rapids, Davenport, Webster City and Ottumwa. In many places they yield sufficient water for hotel and small factory wells, but they can not be relied on to furnish public supplies. In deep wells the Devonian waters should be cased out because their head is lower than that of the Cambrian and Ordovician artesian waters, which will otherwise leak out through the channels opened by solution in the Devonian limestones.

In the southern portion of the Devonian area large fissures and crevices exist in many of the heavier layers. Though the limestone itself is compact and impervious, the drill usually reaches some one at least of the many openings which bring the well into communication with the entire system of circulation and supply it with fresh water at a rapid rate not affected by any drought.

Throughout the larger northern portion of the Devonian area the overlying drift is generally thin, and very many of the best wells end in the lime rock. Plenty of water of the best quality may be obtained by going a short distance into the rock for it, and a driller should not stop before limestone is reached unless the supply coming from the drift is satisfactory in every respect. The rock water of the whole area is under some degree of artesian pressure and rises within easy pumping distance. The expense of pumping and maintenance is slight, and more persons are resorting to it for a pure and permanent supply.

Springs.—The Devonian area is so heavily mantled with drift that springs from the country rock are of little importance. They are not uncommon in the rock-cut valleys in the limestone, but are rarely utilized except for watering stock in the pastures that occupy most of the valley land. For such purposes some of them have been walled and piped out to a tank, but even this care is seldom exercised. Probably the strongest springs of this region are found in Howard and Winneshiek counties, where, owing to the absence of the Niagaran, the Devonian limestones overlap on the Maquoketa shale (p. 88), giving vent to many good streams that feed the headwaters of Oneota and Turkey rivers.

A spring from the Devonian which is worthy of special mention is that from which the public water supply of Cedar Falls was until recently derived. It is located just south of the city in the valley of Dry Run, a small intermittent tributary of Cedar river. It flows perennially from one of the open channels in the rock common to the Devonian in this region, and was sufficient to meet all the demands of the city, with a waste of many times the amount used. Marion is another city similarly supplied by a spring from the Devonian. Water from springs from the Devonian is sold to customers in Cedar Rapids.

QUALITY OF DEVONIAN WATERS.

Perhaps the best evidence of the good quality of the Devonian water is the fact that many wells located where the Devonian immediately underlies the drift and deriving their main supplies from lower strata do not require casings to shut out the hard water of the Devonian. In fact, the Devonian water, as separately known, differs very little from the waters of the deep-lying sandstones (p. 118). Several wells footing in the Devonian, as at Jesup, Lake Mills, and Hanlanton, supply water of good quality. They are, however, shallow and probably reach only short distances into the Devonian and may derive their waters largely from the drift. Farther south wells in the Devonian yield hard waters, as at Gowrie, Grundy Center and Burlington. At all these places the Devonian is deeply overlain by later formations, which may supply the major portion of the hard waters. This source is directly indicated for the city well at Gowrie by the fact that it supplies essentially the same quality of water as the well at Dayton, which is located only a few miles south and foots in the Mississippian. It is not certain that the well at Grundy Center reaches below the Mississippian. Regarding the water from the Devonian, therefore, it may be said, as of the water from the Silurian, that there is little or no evidence to show that it is essentially more heavily mineralized than that of the great sandstone layers of the Cambrian and Ordovician.

WATER IN THE CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

GENERAL CONDITIONS.

The limestones of the different formations of the Mississippian series no doubt absorb large quantities of ground water along their wide belts of outcrop and carry these beneath the cover of the Coal Measures as they sink toward the west. Thus, confined between thick beds of shale, the water is under artesian pressure sufficient in places to bring it to the surface. The flow, however, is meager, and, as with all limestones, is not reliable. The drill may strike or it may fail to strike the water channels. The white limestones of the Burlington, the lower formation of the Osage stage, seem to yield the greatest quantity of water. The only deep wells which report definite water beds in the Mississippian are at Cherokee, Ottumwa, Mount Pleasant, Mitchellville, Des Moines, Bedford, Council Bluffs and Logan. The two cities last named are situated in an area where the Mississippian yields an exceptionally abundant supply.

WATER IN THE KINDERHOOK STAGE.

Over the entire north end of the area in which the Mississippian series forms the country rock the Kinderhook is a fine-grained, heavy-bedded limestone, an excellent water carrier in which all rock wells end and in which they rarely, if ever, fail to secure a large quantity of excellent hard water under sufficient artesian pressure to place it within easy pumping distance of the surface. In some counties, as Kossuth, Humboldt and Wright the artesian head in the Kinderhook is so well developed beneath the impervious clay of the drift that many of the wells flow. The shale beds of the Kinderhook, so unpromising for wells along their outcrop, are of distinct advantage, as they sink below the surface and form part of an artesian system. They prevent the upward escape of waters from the underlying strata and conduct down their dip the waters of the limestones of the Mississippian along their impermeable floor.

WATER IN THE OSAGE STAGE.

Wells.—The drill on penetrating the Osage stage (Keokuk and Burlington limestones) rarely fails to find water in some crevice, especially near the base, before reaching the dry shales of the Kinderhook. Should the driller reach the latter he has the alternative already presented in the discussion of the Niagaran-Maquoketa contact (p. 121). He may continue to drill in search of the deep artesian supplies, though this is impracticable for the ordinary farm or village well, or he may make another boring some distance away in the hope of better success in striking some crevice in the limestone. Before beginning a new boring it is advisable to fill the hole to the base of the limestone and shoot the well with nitroglycerin in an attempt to so shatter the rock that connection may be made with water-bearing crevices and to enlarge the area of intake. Excellent wells have been secured from practically dry holes in the Osage by such means.

Springs.—Springs are not uncommon throughout the Mississippian area where the valleys have been cut into the country rock. They are commonly small and are unimportant except for watering stock in the valley pastures. The most important in southeastern Iowa come from the base of the Burlington limestone, of the Osage stage, where the impervious shales of the underlying Kinderhook check the downward movement of the circulating water and cause it to collect in large quantities in the open spaces in the limestone, whence it flows through some passage to an outcrop. Such springs are common along the base of the Mississippi bluffs in Des Moines and Lee counties and on the lower course of Skunk river, and are of still greater importance farther south in the vicinity of Louisiana, Missouri. These springs are frequently used for household and stock purposes.

WATER IN THE SAINT LOUIS LIMESTONE.

The median bed of the Saint Louis limestone is an important water carrier in Keokuk, Washington, Henry and Lee counties, where it forms the country rock, and in Monroe, Mahaska, Wapello, Jefferson and Van Buren counties, where it is reached by the drill after passing through Pennsylvanian rocks at depths ranging from 200 to 500 feet. It is penetrated in many places in the Pennsylvanian areas on account of the dryness of the Coal Measures or the mineralized condition of their waters. It is in this area that it is known as the "white-water sand rock" and is sought for by all drillers of deep farm wells when a satisfactory sandstone water is not found above. Farther north it is drawn on by a few wells in Hamilton, Webster and Story counties. Locally it produces flowing wells. The upper and lower portions of the Saint Louis are, on the whole, very indifferent water carriers.

WATER IN THE PENNSYLVANIAN SERIES.

DES MOINES STAGE.

Wells.—Owing to the presence of impermeable shales the Pennsylvanian is almost dry. Water is commonly found in the seams of coal but, owing to the abundance of iron and sulphur compounds it carries in solution, is never potable. In fact, it is characteristic of the waters of this division that they are strongly impregnated with mineral matter and in most places are unfit for use.

The chief water bed of the Des Moines stage is the basal sandstone, which has its greatest development in southwestern Iowa. At Council Bluffs it is apparently this terrane which supplies the deep wells of the city, but the yield of these wells is by no means large compared with that of wells tapping Cambrian and Ordovician water-bearing beds in eastern Iowa. At Glenwood water from this sandstone rises to a height of 1,006 feet above sea level and overflows at the surface in the lowest parts of the town, but the yield is not large. At Bedford the water from the same terrane rises to 1,008 feet above sea level. On the whole, it can not be recommended that deep wells be sunk to this sandstone with the expectation of obtaining any considerable amount of water, such as would be required by even a small town.

Small amounts of water may also be found in the sandstone lenses of the Des Moines and Missouri stages, but as these lenses are not continuous over any considerable area, and as their vertical position can not be predicted, no local forecasts can be based on them. They give rise to numerous small flowing wells.

One of the best known lenses of this type is the Red Rock sandstone, which outcrops at the village of Red Rock, in Marion county, in a brilliant red cliff 100 feet in height overlooking Des Moines river. This sandstone occupies less than thirty square miles, but within this area it lies near the surface and furnishes an abundance of good water to all wells penetrating it. It is, however, missed in many wells where it might be reasonably expected, owing to the effects of erosion, which is in part, at least, contemporaneous.

The rapid alternation of impervious shales and porous sandstones underlying heavy drift clays produces conditions favorable to the formation of small artesian basins which frequently give rise to flowing wells. Especially in the larger and deeper valleys like the Des Moines and its major tributaries where the "bottoms" are depressed well below the upland surface, flowing wells with a head of but a few feet above the surface and a delivery of but a few gallons a minute are not uncommon. Stronger flows may be had from the Saint Louis and the Kinderhook. The most notable wells of this type are the Colfax Mineral Springs of Jasper county. These are supplied by a Saint Louis aquifer.

Springs.—Throughout the area where the Pennsylvanian forms the country rock, springs are of little importance. Seeps from shales are common but are small and highly mineralized. A few crevices in outcrops of sandstone lenses produce small springs of excellent water for domestic purposes, but these are rarely strong.

WATER IN THE MISSOURI STAGE.

Wells.—In some places in the area where the Missouri stage forms the country rock a scant supply of hard water is found in the limestone below 100 to 300 feet of drift. The risk of a dry hole is probably greater than in any other area, since below the Missouri stage lies the very uncertain Des Moines stage, and rock wells in this area are therefore comparatively few. There are some excellent exceptions to these general conditions, but the wells of the region are chiefly in overlying drift. The beds of shale are invariably dry. The heavy limestones carry a scant supply of water between the shale beds and this is always hard. The overlying drift is very deep over much of the area, especially on the great Mississippi-Missouri divide, and comparatively few wells reach bedrock.

Cities and towns in the western portion of the province are largely located in the broad river valleys, where an abundance of water may be found at slight depths in the gravel. In the eastern part the interglacial gravels furnish water most copiously. There is little need to resort to the deeply buried rock save on the Great Divide itself, where in many places any ground water is hard to secure.

Springs.—Small springs are common along the deeper valleys at the contact of limestone and shale, but the only rock horizons of importance noted in the Missouri stage area lie along the ragged eastern edge, where the limestone rises almost in an escarpment and is thickly overlain with drift. Here in eastern Madison and Clarke counties good stock springs are numerous.

QUALITY OF CARBONIFEROUS WATERS.

No general statement can be made as to the quality of the waters from the Carboniferous or any of its divisions, save that the quality seems to vary greatly from one locality to another. In a general way it may be stated that the waters of this system are usually more highly mineralized than those of lower ones, and that the mineral matter is greatest in the upper beds of the Carboniferous. A reason for the want of uniformity may possibly be found in the fact that no extensive sand layers or other strata with high power of transmission of water are found in the Carboniferous. It follows that the waters of this system are more local in origin; they are not transmitted from faraway sand plains, as in the lower sandstones, but are derived from the Iowa rainfall, perhaps from the immediate vicinity, and must pass through the drift, in some localities through hundreds of feet of it. There is thus every opportunity for the water to take up any soluble matter that may exist in the drift or immediately under it.

In the area where the Mississippian is the surface rock all wells footing in this series supply soft to only moderately hard water, as far south as Grundy county. Even those in Hardin county, to the west of Grundy, give lightly mineralized waters, though in Hardin county the Mississippian is overlain by the Pennsylvanian. Farther south, however, well waters from the Carboniferous are hard to very hard. Several good examples are found in Tama county. Their waters are not very different from those of the flowing drift wells of the Belle Plaine district, but the hardness of their waters can hardly be credited to the drift, since the mineral content seems to increase with the depth. Near Grinnell, in Poweshiek county, all the wells in the Carboniferous which have been investigated supply hard water containing about 2,100 parts per million of total solids. There are other centers of hard water from this system in Jasper and Polk counties. Wells footing in the Carboniferous in other parts of the state apparently always yield hard waters. It is apparent that with the exception of those in Tama county, wells footing in or passing through the Pennsylvanian yield more highly mineralized waters than those which enter only the Mississippian, and it seems fair to conclude that the waters of the Upper Carboniferous are, on the whole, harder than those of the Lower Carboniferous.

WATER IN THE CRETACEOUS SYSTEM.

DAKOTA SANDSTONE.

Wells.—The Dakota is everywhere a good water carrier, yielding copious and permanent supplies, but the water is commonly mineralized—as a rule highly mineralized. In the northwestern portion of the province the overlying drift is very deep and the sandstone water head, though under slight artesian pressure, is so far below the surface as to make pumping difficult. General difficulty throughout the northern end of the Dakota area is found in the very fine incoherent sand which enters the well, cements itself in the screens and wears out the pumps. In the central and southern portions, however, no such difficulties have been reported, and on the whole, the Cretaceous sandstone may be regarded as the best shallow-rock water carrier in the western part of the state.

Slight artesian pressure is common throughout the Cretaceous area and in the deeper valleys weak flowing wells are not uncommon.

Springs.—Sand-rock water strata like the Dakota are prolific sources of seeps and springs wherever outcrops are found, but as there are few outcrops in the Cretaceous area, because of the deep drift, springs are correspondingly scarce. The most important spring horizon is at the base of the sandstone formation where it overlies the shales of the Missouri stage. The contact is exposed in places in the deep valleys which trench the area in the southwest. It gives rise to strong springs in the vicinity of Lewis, in Cass county, and of Red Oak, in Montgomery county.

QUALITY OF CRETACEOUS WATERS.

Of the Cretaceous little need be said. Apparently all wells penetrating it deeply yield hard waters. A few wells in the northwestern part of the state which penetrate the Cretaceous for a few feet yield fairly good water, but this water is probably from the drift. As a matter of fact, it has been stated and reiterated by those who have been over the ground that experience does not encourage drilling deeply into the rock in the northwestern part of the state.

WATERS OF THE QUATERNARY SYSTEM.

The water-bearing beds in the Quaternary are numerous and their positions are extremely variable. Yet many localities have what the drillers recognize as "first water bed," "second water bed," and in some places even "third water bed," above the country rock. These water beds may in some places be identified by certain well-known sand or gravel beds in the drift, but they vary greatly with locality and in many places are either dry or wanting.

The Quaternary water carriers most frequently recognized and reported are as follows, in order of age from the top downward: Alluvium, Wisconsin drift, loess (including subloessial sands), Iowan drift, Illinoian drift, Buchanan gravel, Kansan drift, Aftonian gravel, Nebraskan drift, and preglacial residual soil.

WATER IN PRE-KANSAN DEPOSITS.

RESIDUAL SOILS.

The residual soil, which occurs in the driftless area and which immediately overlies bedrock in the drift area, is not a good water bearer, but is drawn on in some places on the broad, flat uplands as a source of shallow wells. The supply of water is scant and uncertain and is probably derived in part from the sandy base of the overlying loess.

NEBRASKAN DRIFT.

The Nebraskan (pre-Kansan) till is of no particular value as a water bed and the old soil and forest beds that accompany it render the waters offensive in some places. The sand and gravel layers, however, buried many feet beneath the surface of the ground, form very valuable aquifers, the water being under artesian pressure beneath the relatively impervious till.

AFTONIAN GRAVEL.

The water of the Aftonian gravel is generally pure, wholesome and abundant. In some local areas the presence of decaying organic matter in the old soil and peat beds associated with the gravel imparts a disagreeable odor and taste to the water; in other areas, as in the Belle Plaine artesian basin, the water carries sulphates and other salts in solution in such quantities as to be unsuitable for either boiler or domestic use; such occurrences, however, are exceptional. Wherever the gravel outcrops in the valleys, as in the vicinity of Afton, it gives rise to springs of no mean proportions. On the whole the Aftonian gravel is probably the strongest Pleistocene water bearer in the state.

WATER IN THE KANSAN DRIFT.

The great thickness of the Kansan drift over large areas necessitates its use for domestic and farm wells and it probably supplies more wells than any other water bed in the state, whether of the drift or of the country rock. The supply of many of the shallower wells comes from the sands at the base of the overlying loess and from the gravelly phase in the upper portion of the Kansan, but this supply is extremely uncertain in quantity and generally fails in dry weather. The deeper wells are supplied by the many small sandy lenses and layers and the "veins" in small, more or less open tubular channels scattered through the heavy till. The deep-well water is of good quality, provided care is taken to prevent surface contamination, but it is variable in quantity. Though deep wells in the Kansan are not likely to be affected by drought, neighboring wells may differ very greatly in yield. On the flat divides of the Kansan, where ground water stands high, dug wells are not uncommon, and these are constructed of so large a diameter that a large surface for seepage and an ample reservoir for storage are secured.

Over the much more extensive area of the dissected Kansan dug wells have been superseded by drilled or bored wells, the greater depth more than compensating for the smaller diameter. The windmill or the gasoline engine forms part of the necessary equipment of every farm.

WATER IN THE ILLINOIAN DRIFT.

The Illinoian drift is penetrated by many wells but is not clearly distinguished from the Kansan, which it resembles in its water-bearing qualities.

WATER IN THE BUCHANAN GRAVEL.

Within the area of the Iowan drift the Buchanan gravel lies between the Iowan and Kansan drift sheets and forms a most valuable water carrier, supplying innumerable shallow wells and giving rise to numerous springs wherever it outcrops. Its greatest importance, however, is in the lowlands and in the old filled valleys. On the uplands it is thin and scattered.

The Buchanan gravel has been of great importance in the development of manufacturing in the northeast quarter of the state. Owing, however, to its slight depth and its open texture its waters are easily polluted by organic matter from the surface. They frequently have a slight taste and leave a brown stain due to compounds of iron in solution.

WATER IN THE IOWAN DRIFT.

Water occurs in the Iowan drift in small sandy layers and lenses and in the small "veins" of the till. From these it seeps into the wells slowly but constantly, supplying them with a moderate amount of hard water, which will be pure provided care is exercised to prevent the entrance of surface water and its accompanying contamination. Owing to the thinness of the drift and the strength and purity of the country-rock aquifers below, rock wells are very commonly replacing wells in the Iowan drift.

WATER IN THE LOESS.

The loess was formerly an important source of supply for farm wells throughout the state, but drainage and cultivation have so lowered the ground-water level as to greatly lessen its importance. The subloessial sands lying beneath the loess and over the till near the Iowan margin yield a somewhat more plentiful but very uncertain supply. Many shallow wells dug in sloughs and other moist places still utilize this source for stock water. Both the loess and the subloessial sands are extremely liable to contamination from surface waters, cesspools, etc., and should be avoided for domestic purposes, especially in towns or villages and in the neighborhood of barnyards on the farms.

WATER IN THE WISCONSIN DRIFT.

In the Wisconsin drift shallow wells are general, the supply being obtained, as in the other drifts, from sandy layers and "veins" in the till, but they are especially liable to pollution owing to the prevalence of surface waters. The better drift wells go below the base of the Wisconsin and draw their supply from underlying beds of the loess or lower horizons.

WATER IN ALLUVIUM.

The sands and gravels of the alluvium yield an inexhaustible supply of good water at depths ranging from 15 to 100 feet. They may be reached throughout the "first bottoms" and in places on the "second bottoms" of the larger rivers and tributaries. Water is generally obtained at slight cost by means of open or driven wells and in larger quantities for city supplies through infiltration beds and collecting galleries. These deposits furnish the chief underground water supply for several large cities within the state.

In towns and cities these alluvial waters are generally contaminated from the surface or through cesspools. The public supply should always be taken at some point above the city and private wells should be closed. All such supplies, when used for drinking or domestic purposes, should be carefully tested and guarded.

UNDERGROUND-WATER PROVINCES OF THE QUATERNARY.

The regional differences between the waters of the different drifts are not so characteristic as to form well-defined provinces. The limits of the several water-bearing strata are, however, determined by the limits of the drift sheets to which they belong or are related as interbedded deposits. These limits do not coincide with those of the districts into which the state has been divided and for specific consideration of drift waters it seems advisable to redivide it on the basis of drift sheets coextensive with the topographic areas already described (p. 49), and known as the Wisconsin, Iowan, Illinoian and Kansan drift provinces and as the driftless province.

DRIFTLESS PROVINCE.

In the driftless province water is obtained from the alluvium, the loess, and the residual soil. The loess and the residual soil supply shallow wells on the broad, flat uplands, but the yield of both is so scanty that most good wells are sunk to one of the numerous and excellent country rock horizons, which may there be reached at comparatively little expense. On the flat valley floors shallow wells draw an abundance of good water from the gravel and sands underlying the alluvium. Springs from the outcropping rocks of the valley sides are so numerous as to greatly decrease the number of wells necessary.

KANSAN PROVINCE.

In the Kansan drift province water may be obtained from the alluvium, the loess, the Kansan drift, the Aftonian gravel, and the Nebraskan drift. The great thickness of the Kansan drift and the presence of Pennsylvanian rocks immediately underneath a large part of this area cause the Kansan drift to be one of the most fully utilized water beds of the state, even though its yield is scanty. Owing to the depth of the drift and the scanty yield, deep-bored wells are now becoming common, especially in the vicinity of the Mississippi-Missouri divide. Many wells in the southeastern district penetrate the Aftonian gravel and are abundantly supplied. The base of the drift, where this is sufficiently shallow to be reached by ordinary farm wells, is a favorite source of supply; it probably includes the Nebraskan as well as the Aftonian horizon.

Under the broad floors of the valleys the flow is ample for the cities of several thousand people located thereon. The waters are obtained by wells fitted with drive points and Cook strainers. On the broader uplands many of the shallowest wells draw a small supply from the sandy layer in the base of the loess immediately overlying the impervious till.

ILLINOIAN PROVINCE.

In the Illinoian drift province water is obtainable from the loess, the Illinoian drift, the Kansan drift, and the Aftonian gravel. The Illinoian and Kansan drifts are not clearly differentiated in the wells; both are used indifferently by wells, and even the loess affords a meager supply for many wells. The better drift wells draw from basal gravels, probably those of Aftonian age.

IOWAN PROVINCE.

In the Iowan drift province water is obtained from the Iowan drift, the Buchanan gravel, the Kansan drift, and the Aftonian gravel. The Iowan and Kansan drifts are both generally used, but the strongest wells draw from the Buchanan or Aftonian gravels. Such wells are generally best developed on lowlands and in old stream channels. The loess supplies some shallow wells on the margin of the area where it overlies the edge of the Iowan drift.

WISCONSIN PROVINCE.

In the Wisconsin drift province water is obtainable from the Wisconsin drift, the loess, the Buchanan gravel, the Kansan drift, and the Aftoniān gravel. The porous loess is very generally recognized where present and is the best shallow-well aquifer in the area. Owing to the immaturity of the topography the ground-water level is high, wells are generally shallow, and all not well guarded are liable to surface pollution.

CHAPTER IV.

ARTESIAN PHENOMENA.

BY W. H. NORTON.

DEFINITION OF THE WORD "ARTESIAN"

The word "artesian" has been used with several meanings, but, in accordance with the usage now prevailing, artesian waters include not only the water of flowing wells, but also well waters that rise to a considerable height within the tube under hydrostatic or artesian pressure. Thus, in the deeper river valleys of Iowa the head of the water from the Paleozoic aquifers is higher than the valley floors, and the water overflows in natural fountains, many of which are of considerable height. On the uplands, however, water from the same water beds, rising through the same strata, under the same driving force and with the same head, fails to reach the surface of the ground. The important and definite fact is that under hydrostatic pressure, the water rises to or nearly to the surface. In classifying ground waters it is comparatively unimportant whether the surface of the ground at any given point is slightly above or below the level to which the water from the deep source rises.

HEAD OF ARTESIAN WATERS.

DEFINITION.

The water beds of the Iowa artesian slope dip southward from their outcrop on the high lands of the states adjacent on the north. The water confined within these beds is therefore under hydrostatic pressure, much as is the water in a city's mains from the weight of the column of water in the standpipe. Under this artesian pressure it rises in deep wells far above the level of the water bed. It may fall short of reaching the surface of the ground, or it may overflow and in an open tube connected with the well may even rise and maintain itself at a considerable height above the well mouth. The height at which artesian water stands under hydrostatic pressure is called its static level or head. It may be expressed in its relation to sea level, to the level of the water bed, or to the level of the well mouth. As artesian wells may head either above or below the well mouth, they are divided into two classes, flowing and nonflowing.

MEASUREMENT.

The head of flowing artesian wells may be measured in two ways. The pressure may be measured at the well mouth, in pounds per square inch, by means of a gage, and the head may then be computed in feet. As a column of water 1 inch square and 2.3 feet in height weights 1 pound, the number of pounds pressure at the well multiplied by 2.3 equals the head in feet. Somewhat less conveniently the head of flowing wells may be measured by tubing, coupled water tight, and carried up until the water stands at the top but does not overflow. The size of the tube is immaterial. The test is most easily made with a hose of any convenient diameter, carried up a ladder or trestle, since owing to its flexibility, it may be lifted or lowered until the exact head is obtained and the cuttings and coupling needed with metal pipe are obviated.

To obtain the true hydrostatic balance a day or even several days may be necessary, and for this as well as for other reasons the test is most conveniently made with the pressure gage.

FACTORS AFFECTING HEAD.

ELEVATION OF AREA OF SUPPLY.

The head or static level depends on several conditions, chief among them being the elevation of the intake area, or area of supply, where the water bed or beds outcrop and gather their water from the rainfall. The area of supply of the principal water beds of the Iowa artesian system—the Cambrian and Ordovician sandstones—lies for the most part in southern Minnesota and Wisconsin, where it comprises about 14,500 square miles. The area presents a considerable diversity in elevation but in few places is more than 1,200 feet above sea level. With a gathering ground whose altitude is relatively so low, the water beds of Iowa furnish only a moderate pressure to their artesian waters. The enormous pressure of the South Dakota artesian wells, for example, due to the high gathering ground on the flanks of the Black Hills—pressures which equal heads of 400 feet in places, and which can be utilized for power in manufacturing plants or to supply fire protection for a city—are not to be expected in Iowa.

ELEVATION OF SURFACE AT THE WELL.

The highest heads, relative to the top of the well, are found where the elevation of the ground surface above sea level is least. From Des Moines river eastward the artesian wells situated in the deeper valleys are flowing wells, and the wells of the deepest valley, that of the Mississippi, register the greatest pressure. The following table exhibits the maximum initial head reported from the wells in the Mississippi valley from north to south.

Town.	Head above low water in river.	Head above sea level.
Lansing	88	690
McGregor	87	694
Dubuque	153	740
Sabula	70	656
Green Island	84	665
Clinton	66	632
Davenport	103	643
Fort Madison	136	638
Burlington (on bluffs)	136	647
Keokuk	190	667

On the other hand, on the uplands of the state the water generally fails to rise to the top of the wells, although it generally rises higher (above sea level) than it does in the valleys.

AGE OF WELL.

Owing to various causes, some remediable and some irremediable, the artesian head in any given well commonly decreases with lapse of time. Any plans to utilize the pressure for fire protection, as at Sabula, or for running dynamos for city lighting, as at Keokuk, should take account of this fact.

After the first wells are drilled in any locality, it is often difficult to determine the true head. Leaks are liable to develop by which more or less of the water escapes laterally from the drill hole, and the head of the water is correspondingly reduced. As other wells are drilled from time to time and are left to discharge freely, the head is further lowered, and it is difficult to determine the pressure in any given well, unless all the wells can be closed for the occasion. In a number of places the flow of a new well on lower ground has drawn down the head of other wells in the neighborhood.

HYDRAULIC GRADIENT.

Most water-bearing formations are cut at greater or less distances from their outcrops by river valleys, into which more or less of their water escapes. Such leakage necessarily reduces the pressure, or head, of the water, the effect increasing as the point of escape is neared. It has been found that, owing to this and to certain other factors (such as the friction of the rock particles through which the water percolates), the height to which artesian water will rise above sea level declines more or less uniformly from the intake area to the point of escape. This decline is known as the hydraulic gradient.

HEAD AS AFFECTED BY THE GROUND-WATER LEVEL.

Under certain conditions the height of the ground-water level of the area and the head of minor and higher artesian aquifers tapped by the drill may affect the head of a well.[1] The effect of these agencies is illustrated in the map (Pl. I; in pocket). In Iowa the hydraulic gradient declines from Boone eastward to Clinton on Mississippi river, 310 feet in 190 miles, the surface of the ground falling 550 feet in the same distance. (See Pl. XI.)

RELATIVE HEADS OF IOWA AQUIFERS.

When a deep well is being sunk, the question is often asked whether water under greater pressure, giving a higher head,

[1]Chamberlin, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 125-173.

will be found at greater depths or whether the deeper water will be under less pressure, causing the well perhaps to lose its flow. It is greatly to be regretted that the data at hand so seldom permit a conclusive answer to this question. When a deep well penetrates several different water beds, the head of each bed should be tested as the drilling is in progress, but as this testing of flowing wells involves considerable trouble and some expense it is seldom if ever done. In nonflowing artesian wells the fluctuation of water in the drill hole due to the different heads of different aquifers can be readily observed, but in few wells have such observations been made and placed on record. When the head of a well is given, it is seldom known by what particular water vein the pressure is determined or to what extent the head has been lowered by the discharge of other wells.

The chief aquifers of the Iowa water system, the Saint Peter sandstone, Prairie du Chien stage, Jordan sandstone, and Dresbach sandstone and underlying Cambrian formations, afford considerable evidence that the lowest water beds give the highest head. Thus at Dubuque the original heads of the wells ending above the Dresbach sandstone seem to have been from 700 to 740 feet above sea level, whereas the head of wells which tapped the Dresbach or underlying Cambrian sandstone reached perhaps 753 feet. At Waterloo the head of the water from the Saint Peter is given at 865 feet above sea level, and that from the water beds between the Saint Peter and the Dresbach at 867 feet, but at Davenport the beds below the Saint Peter seem to have a somewhat greater head. In the deep well at Holstein the waters from the higher formations, including the Saint Peter and probably the Jordan, stood 325 feet below the curb; when the Dresbach was struck the water rose to 270 feet below the curb. On the other hand, in some nonflowing artesian wells, as at Pella, Centerville, Burlington, and Anamosa, the water seems to have maintained about the same level while the drill was passing through the various Cambrian and Ordovician water beds. At Ottumwa the aquifers of the flowing wells seem to have a common head at about 700 feet above sea level. At Boone, on the other hand, the head of the water of the Saint

Peter is 1,080 feet above sea level, but that of the main vein in the deeper sandstone is 940 feet above sea level, 140 feet lower.

The head of the water beds above the Saint Peter may be either higher or lower than that of the Cambrian and Ordovician beds. In upland wells of northeastern Iowa the head of the water from the Niagaran, the middle part of the Maquoketa, the Galena, and the Platteville is higher than that of the water from lower aquifers. Thus at Sumner the waters from the Middle Maquoketa and the Galena stood 18 feet below the curb, and those from the Cambrian and Ordovician beds 144 feet below. This difference is especially marked in the extreme northeastern counties where the main river valleys dissect the Saint Peter and even the Jordan and permit water to escape. Thus at Calmar the water from the Galena and Maquoketa rises 76 feet higher and at Postville 170 feet higher than the water from the Saint Peter. In wells outside of this area and in valley wells within it the water from the Cambrian and Ordovician aquifers usually rises higher than that from superior terranes. Thus at Vinton the water from the Saint Peter rises 38 feet higher than that from the Devonian, and at Davenport it rises 10 feet higher than that from the Galena. At Holstein the water from the Saint Peter rose 40 feet and at Osage about 10 feet above that from higher water beds.

The head of the Dakota sandstone in northwest Iowa seems to be higher than that of lower beds, exceeding that of the Saint Peter at Cherokee by 120 feet. In fact, the reported high head of a number of deep wells in this part of the state may be largely due to the Dakota waters.

The map showing artesian head (Pl. I) presents graphically the scanty data at hand, but forecasts must not be based on it with undue assurance. The head of any well depends on a number of factors and is perhaps the least predictable matter connected with the subject. In a number of the wells the head probably depends on that of waters of drift or country rock. The map presents, however, the salient facts of the decreasing head with increasing distance from the area of supply and the heightening influence of the ground waters of the uplands in central and northwestern Iowa.

YIELD OF ARTESIAN WELLS

MEASUREMENT.

No deep-well data are more unreliable than those relating to yield. The reported discharge of flowing wells is seldom more than a loose estimate and often, no doubt, a gross exaggeration. For pumped artesian wells, the amount delivered by the pump can and should be calculated with considerable accuracy and may be assumed to be the capacity of the well when the latter does not exceed the capacity of the pumps. The yield of flowing wells may be estimated by the flow over a weir, by a current meter set in the pipes or by the time necessary to fill a receptacle of known capacity. Where the yield is moderate measures as small as hogsheads may be used for this purpose. Slichter[1] describes a very simple method of determining the yield of a flowing well devised by J. E. Todd. Pumping tests should last at least 24 hours and should be conducted with pumps of adequate capacity.

PERMANENCE OF YIELD.

FACTORS AFFECTING YIELD.

The length of time which an artesian well may reasonably be expected to remain in service, the causes which impair or ruin it, and their remedies are questions of vital importance on which some light should be shed by the collated history of the hundreds of deep wells of the Iowa field, some of which have been in operation for a quarter of a century.

It may naturally be expected that, like any other mechanism, this apparatus for bringing water from its subterranean sources to the surface is liable to deteriorate with age, to need from time to time repairs of various kinds, and, indeed, to break down from one cause or another and to become altogether useless. To know the points of weakness in this mechanism, which is not quite so simple as it at first view may seem, and to know the dangers which threaten it is absolutely necessary if the well is to be so constructed and so cared for as to insure its permanence.

[1]Slichter, C. S., The motions of underground waters: Water Supply Paper, U. S. Geol. Survey, No. 67, 1902, pp. 90-93.

A deep well drilled in Iowa for a quarter or a half mile, straight toward the center of the earth, passes through rocks of various kinds. Some are strong and unyielding; some are mobile or plastic, creeping under the enormous weight of overlying rocks they carry and thus constricting or closing the drill hole. Some are brittle and fragile, and from such rocks movements of water in the well dislodge fragments which, on falling, leave cavities along the bore hole and, accumulating at the bottom, choke the discharge of the water beds situated there. Some are close-textured, some are spongy and porous, and some are creviced. Some are dry and some are water-logged, and of the latter class some contain good water and some water so highly mineralized as to be unpotable or injurious to the health. Of the good waters, some may be under so little pressure that another flow under higher pressure will drive them back and escape through their channels if left free to do so. The main water bed may consist of loose and crumbling sandstone, which with time breaks down and forms a chamber, roofed, perhaps, with shale, which, when left unsupported, caves in and closes the waterway.

For some distance from the surface the well commonly penetrates incoherent material incapable of standing in a solid wall. A casing is therefore inserted and bedded in solid rock. But unless the juncture of casing and rock is water tight the ascending water of a flowing well will in time find a way through it out of the drill hole.

Finally, even if the well is perfectly constructed and the supply in the water bed is large, the yield may be diminished through overdraft by other wells put down in the vicinity.

Permanence of an artesian yield, therefore, depends (1) on the construction and care of the well itself; (2) on the character of the water bed from which it draws; and (3) on the combined draft on the water bed by all the wells in the vicinity.

FACTORS RELATING TO THE WELLS.

CASING AND PACKING.

Heavy iron casing is inserted where the well passes through weak rocks liable to cave or creep and where it passes through aquifers containing salt or bitter water or good water under so low a head as to permit lateral escape of the main flow. The upper casing is carefully packed at the base to prevent any escape of water. Where the water bed is of weak rock it is protected with strong casing perforated to admit the entrance of water.

All these precautions are taken if the job is thoroughly done. But as casing is costly, as the nature of the rocks to be penetrated is in many places not well known, as the heads of the various water veins are not tested—for all these and for less excusable reasons it is not seldom that some of these points of danger are left unguarded. The upper casing is left unpacked but is simply grounded on bedrock, which in Iowa is usually limestone. This soluble rock gradually decays about the base of the casing, a thin thread of water escapes into the surrounding overlying sands or shattered rock, and the opening is enlarged by solution until the leakage is sufficient to stop the flow of the well.

Uncased shales, although to all appearances at first sufficiently firm, may yield to the action of the water passing over their exposed surface and cave within a few years after the completion of the well. Limestones, although strong enough to stand indefinitely, may contain crevices, openings, and porous beds of which the driller is untirely unaware. Water from other pervious beds under heavy pressure is driven into these passages until most of it escapes through these leaks and the well ceases to flow.

The main water bed may be a loose-grained sandstone, which, if not cased, gradually breaks down and tends to fill the well with its detritus. It may be a fine-grained as well as a loose-grained sandstone, and even when the well is cased the grains may be fine enough to pass through the perforations of the casing and the strainers, likewise causing the drill hole to fill. Where casing is sunk to prevent leakage the pressure under which it is driven down may split or break it at the joints, and through these breaks the water may escape.

DIAMETER OF DRILL HOLE.

Very obvious causes of difference in the yield of artesian wells are differences in the capacity of the drill hole or its casing.

The cross section of a tube varies as the square of the diameter; thus, disregarding other factors, an eight-inch pipe would carry 16 times as much as a two-inch pipe. But the larger the diameter the less the frictional resistance; hence the difference in favor of the larger pipe is still greater. Taking into account both cross section and frictional resistance, the discharge of pipes varies as the 2.5 power of the diameter.[1]

The yield of a deep well is controlled, not by the maximum diameter of the bore hole—that at the well mouth—but by the diameter of the hole at the water-bearing stratum. In sinking deep wells it is necessary from time to time to reduce the diameter of the drill hole. The first deep well at Boone, for example, which began with a diameter of eight inches, was reduced four times, and reached the bottom at 3,010 feet with a diamter of three inches. The Greenwood Park well at Des Moines, 3,000 feet deep, beginning with 10 inches, reached the bottom with three inches. For this reason and because of the rapid increase in the cost of drilling with increase of depth, it may be concluded that the limit of profitable drilling lies under rather than over 3,000 feet. The cost of tapping a water bed at this distance from the surface with a drill hole large enough to carry its waters is so great that the outlay is seldom warranted.

Large holes also have an advantage in that they offer a larger surface of transmission within the water rock, and thus give a more generous yield, but this increase is comparatively slight. Thus, of two wells, each sunk 100 feet in water beds presenting similar conditions of pore space, pressure, etc., a 6-inch well yielded 36 cubic feet a minute and a 12-inch well only 41 cubic feet a minute, although its carrying capacity is four times as large.[2] Several small wells will secure a larger inflow than one large well. Furthermore, to secure the maximum efficiency of a number of wells, they should be spaced as widely as practicable so as to interfere as little as possible with one another.

[1]Slichter, C. S., op. cit., p. 84.
[2]King, F. H., Principles and conditions of the movements of ground water: Nineteenth Ann. Rept., U. S. Geol. Survey, pt. 2, 1899, p. 285.

FACTORS RELATING TO THE WATER BEDS.

PRESSURE.

The yield of flowing wells from beds of equal porosity varies with the pressure of the water at the point of discharge, or with the difference between the surface level at the point of discharge and the level to which the water will rise by artesian pressure. The relatively large yield of the deep wells of the valley towns of Iowa compared with that of upland wells is explained by their greater head, and the assumption made by some persons that natural cracks and fissures of great extent coincide with river valleys is quite gratuitous. The law is well illustrated in a test made of a flowing well at Hitchcock, Texas, whose water rose about thirty feet above the curb, the point of discharge being taken at different heights and therefore at different distances below the static level. When the point of discharge was 25.35 feet above the curb the well yielded in a given period 8,022 gallons, and when it was 0.76 foot above the curb it yielded in the same period 95,000 gallons. This change, which was equivalent to increasing the head from 4.65 feet to 29.24 feet, increased the flow of the well nearly twelvefold. In the location of wells this law of pressure variations should be considered. Other things being equal, the lowest ground available should be chosen as the site of the well, for here the head and discharge will be the greatest.

To the same law is due the greatly increased flow when pumps or air lifts are used. Thus, at Charles City, the yield of the city well, whose estimated natural flow was 200 gallons a minute, was increased by a vacuum of seven pounds to 900 gallons per minute. At Mason City, Waterloo and Dubuque greatly increased flows are obtained by means of air lifts. Advantage is taken of the same principle when the pumping cylinder is set low in non-flowing wells. At Ames a test made with the cylinder set 270 feet below the ground gave a maximum discharge of 7,400 gallons an hour; at 149 feet below the surface it gave 5,000 gallons an hour; and 105 feet below the surface it gave only 3,525 gallons an hour.

Pressure is a controlling factor in the transmission of water through porous rocks. Experiments have shown that the yield of porous sandstone varies with the pressure, but doubling the pressure usually more than doubles the amount of water transmitted. The moderate pressures of the Iowa artesian basin suffice to overcome the frictional resistance and to drive the water on its way but are not sufficient to force such immense yields as are reported from wells of the Dakotas. The moderate pressure may also result in a comparatively rapid lowering of the head in any local area, for the slower the transmission the more rapidly will the area be depleted under a given draft.

THICKNESS OF THE WATER BEDS.

Few if any wells yield as much water as would be indicated by the theoretic capacity of their pipes and the velocities due to their pressures. This is because the water is delivered to the pipe through porous rock through which water seeps from distant sources under great frictional resistance. The yield depends, therefore, on a number of conditions relating to the rock constituting the water beds. It depends on the amount of surface exposed in the drill hole within the water bed. When the bottom of the hole barely touches the water bed, or an unperforated casing extends to the bottom of the well, this surface is at a minimum and gives a minimum yield, for it is then merely the area of the circle whose diameter is the diameter of the bore. When the entire water bed is penetrated and the hole is uncased, the surface of transmission is at a maximum and gives a maximum yield, for it is then the surface of a cylinder whose height is the thickness of the water bed. Thus a thick water bed will not only hold and carry more water than a thin one, but may also deliver more water to a well. Several water beds will yield more than a single water bed of less than their combined thickness. The thickness and the number of the Iowa aquifers therefore constitute one cause of the large flow of the wells. It follows that a deep well should be sunk completely through any given water bed, and that the more water beds it traverses the larger will be its yield, provided of course that certain beds do not drain away the waters of others because of difference in head. Several Iowa wells that have stopped in the Saint Peter sandstone would have obtained a much more copious yield if they had been carried through the Prairie du Chien and the Jordan.

On the other hand, there are places where the lower waters should be left undisturbed even though the yield would be increased by drilling to them. At Cedar Rapids and at McGregor the first wells drilled encountered salty and corrosive waters in the Cambrian sandstones, and wells drilled later in these towns were, therefore, stopped before they reached the horizons at which the deleterious waters were obtained. In northeastern Iowa, along the Mississippi valley, the lowest of the aquifers, the Dresbach and underlying Cambrian sandstones, is drawn upon freely; but outside of this area the expense of reaching it, and the probability of finding its waters highly mineralized, are so great that it is generally advisable to stop the drill at the base of the Jordan sandstone.

In loose, friable sandstone it may be necessary to case through the water bed. In such wells the casing should be perforated through the entire thickness of the water bed.

TEXTURE AND POROSITY OF WATER BED.

Yield depends very largely on the texture and porosity of the water rock. Gravel yields its store of water more freely than coarse sand, and coarse sand than fine sand. Doubling the effective size of grain quadruples the yield. Stratified rocks transmit water most readily parallel to their bedding planes, and this fact gives an additional reason for the large yield of wells which penetrate water beds deeply and are fed from the sides by horizontal currents, as compared with the yield of wells which touch only the upper surface of the water bed and are fed from the bottom by currents rising transverse to the bedding planes.

The main sandstone aquifers of the Iowa artesian system include many highly porous beds through which water seeps freely into wells. Their grains are moderately large, are exceptionally smooth and well rounded, and are fairly uniform in size, thus increasing the pore space, as few minute grains are packed in the interstices of the larger grains. Cements filling the pore spaces to a greater or less extent are practically absent in many of these water-bearing beds. In consequence of these conditions, the sandstone aquifers of Iowa yield exceptionally abundant supplies.

With increasing distance from outcrop and with increasing depth and slackening of the ground-water circulation clogging and filling of pore spaces may be expected in any water-bearing terrane accompanied by restriction of the water channels to special horizons kept open after the remainder of the rock of the terrane has become impervious by cementation. The yield of aquifers, such as the Saint Peter and the Jordan, can not be expected to be as great where they reach great depths in central Iowa as it is in northeastern Iowa, where they lie much higher and their circulation is far more active.[1]

CREVICES IN THE WATER BED.

The yield of the artesian wells of Iowa is increased by the fact that the waters flow not only through the pore spaces of sandstones and loose-textured limestones but through the fissure cracks and crevices that are common in limestones and occur even in many sandstones. The existence of these passages might be inferred from general considerations and from experience elsewhere, but in the Iowa field it has frequently been proved by the sudden drop of the drill, by the deflection of the drill, and by the underground disappearance of drillings. Many of these passages through limestone are in connection with the sandstone aquifers.

Between the Saint Peter and the Jordan sandstones lies a heavy body of creviced limestone, more or less arenaceous and in places interleaved with layers of porous sandstone, and below the Jordan sandstone lie the limestones of the Saint Lawrence formation. Throughout this entire body of rock, from the base of the Platteville to the summit of the impervious beds of the Saint Lawrence, artesian waters may participate in a common movement. Water sinks or rises from sandstone to limestone, and vice versa. Where its course lies in the solution passages in limestone its velocity is greatly increased, and where the drill penetrates such crevices the flow is proportionately abundant. Even the delivery of the sandstone is no doubt increased by communication with the more open ways of the limestones.

[1]The Saint Peter, struck at Nebraska City, at a depth of 2,783 feet, although 64 feet thick, was found dry.

CLOGGING OF THE WATER BED.

The yield of some wells diminishes because the water bed becomes clogged. Fine material in the rock is carried little by little toward the well and accumulates immediately about the drill hole in the interstices between the larger grains, thus lessening the porosity and the transmission capacity of the aquifer and lessening correspondingly the yield of the well. The danger is believed to obtain especially with incoherent sandstones which have large diversity in size of grain and contain material of siltlike fineness, either interleaved or disseminated through it. In the main water beds of Iowa—the Cambrian and Ordovician sandstones—clogging to any noticeable extent from this cause should be rare. In the artesian wells at Savannah, Georgia, an effectual remedy for clogging was found in forcing a strong flow down the well by means of fire engines.

Clogging may be the result of the growth of microscopic plant life and gelatinous deposits of iron, as in Linwood Park well at Dubuque, where the obstruction was a fibrous growth, probably of Crenothrix, and where churning an iron rod in the well doubled the diminished flow.

OVERDRAFT ON WATER BEDS.

Artesian wells may fail because of overdraft. In many large towns and cities the fact that a copious supply of water, whose purity is above suspicion, can be obtained at moderate cost, leads to the multiplication of wells beyond the local transmission capacity of the aquifers. The head of old wells gradually diminishes and that of new wells drilled from time to time fails to reach the initial head of the wells first drilled. The opening of a well of unusually large yield, resulting from its exceptionally large diameter or from its location on low ground, may cause a sudden fall of pressure in all the wells of the locality.

Finally, the artesian head in a locality may be so reduced that all the wells cease to flow and all require pumping. The cause of this lowering of artesian head is simply that more water is being drawn from the water beds at this place than can flow in. The storage capacity of the artesian basin is not overdrawn, nor is there a deficiency in the rainfall and absorption over the area of supply of the artesian system. The limiting factor is the transmission capacity of the water-bearing strata at that locality. For such a condition there is obviously no remedy. The most that can be done is to guard against any waste of the water, either above ground or by leakage below the surface. The real overdraft may be due not to necessary consumption but to leakage from a number of wells.

In the towns and cities of Iowa where many wells have been drilled loss of pressure has been noted too generally to be accounted for by deterioration of individual wells. Such a loss, for instance, has occurred at Dubuque, Clinton, Davenport, Burlington, Keokuk and elsewhere (p. 155). In none of these places has the decrease been sufficient to wholly prevent artesian flow, though in several pumps are used to increase the yield.

REMEDIES FOR DECREASED YIELD.

The first step in remedying decreased yield is to discover whether the error is not in the well itself. Even when properly constructed the mechanism of a deep well can not be expected to last indefinitely. Packing may deteriorate with age and leaks develop about the lower end of the uppermost casing. Casings in time rust out, and under the chemical action of certain waters this deterioration may be rapid. The casing may be attacked at the joints, the screw threads becoming so rusted that when the casing is drawn to recase the well each joint has to be lifted separately; or the water may corrode the sides of the casing, perforating it with holes as large, sometimes, as a 5-cent piece, thus causing leakage. The remedy here is to recase the well.

In a number of Iowa wells where this has been done the initial yield has been restored. Thus the Atlee well, at Fort Madison, used for a public fountain in the street and for a private fountain on the grounds of the owner, which lost its head of 55 pounds, is said to have had this entirely restored by recasing. Unfortunately a well may be drilled a little out of vertical and the insertion of a casing is impossible when a need of repairs arises. An example is afforded by the deep well at Monticello, one of the oldest artesian wells of the state, which furnished excellent water but had to be abandoned because the crooked bore hole prevented the essential repairs.

In wells ending in sand the screen at the foot may become incrusted and the flow of the water stopped. The remedies for this are discussed on pages 219-226.

In many oil wells an increase in yield has been obtained by torpedoing with nitroglycerin. This method has not been attempted with the Iowa artesian wells, nor, indeed, can it be recommended except as a last resort where drill holes would otherwise be failures. In close-textured limestones the shattering of the rock under the torpedo may not extend to any passageways. It must be remembered that an artesian well is expected to be far more permanent than an oil well. Torpedoing a well usually not only makes it impossible to sink it deeper but also to repair it at any time.

Still less excusable is the use of nitroglycerin in repairing drill holes. At Vinton in 1910 two adjacent deep wells needed repairs of the same nature and extent. In attempting to pull a corroded casing in the north well several shots of high explosives were fired and the drill hole was so damaged that the total cost of the repairs exceeded $7,400, whereas the repairs on the south well made by an experienced company cost but $1,600.

STATISTICS OF DECREASED YIELD.

The following tables present all the information which has been gathered concerning the deep wells of Iowa which have been abandoned or whose yield has decreased:

Artesian wells whose yield has diminished

Location	Depth	Date of completion	Date when diminution first noticed	Head Above or Below Curb: Original	Head Above or Below Curb: Present (1908)	Yield: Original	Yield: Present (1908)	Remarks
	Feet	*Year*	*Year*	*Feet*	*Feet*	*Gallons per min.*	*Gallons per min.*	
Cedar Rapids:								
City well—								
No. 1	2,225	1883	1901	28	2	250	150	Well plugged at 1,450 feet; loss gradual; casings rusted; no repairs.
No. 2	1,450	1883	1901	28	2	250	150	Loss gradual; casings rusted; no repairs.
No. 3	1,450	1883	1901	28		250		Casings rusted; no repairs; not in use.
Young Men's Christian Association well	1,450	1894						Casings rusted; no repairs.
Clinton:								
Clinton Paper Co.	1,065	1883	1895	42	.083			Loss gradual; casing rusted; recased to depth of 160 feet in 1896, but no improvement noted.
Chicago & North Western Ry.; near station	1,159	1896	1895	12	*12		500	Loss gradual, leaked about old packing; yield increased by recasing and repacking in 1905.
Chicago & North Western Ry.; South Clinton			1908		—20			Loss sudden on completion of well of Sugar Refining Co.; flows as usual when the well of sugar company is closed; no repairs.
Amana:								
Woolen mill	1,640	1883	1893	30	20	200	+50	Loss gradual; repacked in 1889.
Burlington:								
Murray Iron Works	831	1903		92 / 69	46			Yield decreased from time to time as other wells were drilled; no repairs.
Iowa Soap Co.	509	1904	1905	83	4			Loss sudden when Clinton Copeland well was sunk; no repairs.
Sanitary Milk Co.	487	1905	1905					Head decreased 46 feet when Clinton Copeland well was sunk; no repairs.
Smith and Palton	460	1905	1905	80		40		Loss sudden, presumably owing to drilling of other wells; no repairs.
Council Bluffs:								
Chicago, Milwaukee & St. Paul Ry.	750						+ 3½	Loss gradual and continuous; cause unknown. No repairs.

Artesian wells whose yield has diminished—Continued

Location	Depth	Date of completion	Date when diminution first noticed	Head Above or Below Curb		Yield		Remarks
				Original	Present (1908)	Original	Present (1908)	
	Feet	*Year*	*Year*	*Feet*	*Feet*	*Gallons per min.*	*Gallons per min.*	
School for the Deaf—								
Well No. 1	1,090	1886	----	50	10	59	+ 3 15	Loss gradual; increased flow temporarily by deepening, cleaning, and recasing in 1893.
Well No. 2	1,100	----	----	----	----	----	+ 6 30	Loss gradual; no repairs.
Geisse Brewery	1,114	----	----	----	----	----	(†)	Casing rusted.
Davenport:								
Woolen mills	1,053	1890	----	87	1	----	----	Flow temporarily increased by recasing in 1895 and in 1901.
Davenport Packing & Provision Co.	1,100	1893	----	46	7	----	----	
Gas works	1,200	1891	----	52	4	----	----	Loss gradual.
Glucose factory	2,101	----	----	81	24	----	----	
Do	2,105	1889	----	81	----	----	----	
Do	2,107	1892	----	81	24	----	----	
Do	1,500	1876	----	----	24	----	----	
Independent Malting Co.—								
Well No. 1	1,285	1896	----	----	9	----	406	Loss sudden, due to pumping of other wells.
Well No. 2	1,285	1904	----	----	9	----	400	Do.
Kimball House	1,100	----	----	58	----	----	----	Flow ceases when wells of glucose factory are used; cleaned out and reamed.
Dubuque:								
City well, Eagle Point—								
South well	1,308	----	----	23	10	----	----	Under air lift said now to yield 435,000 gallons per day.
North well	1,306	----	----	23	10	----	----	Under air lift said now to yield 1,208,000 gallons per day.
Schmidt Brewery	886	1891	----	----	----	----	----	Decrease caused by interference; flow ceased in 1908.
Linwood Cemetery—								
No. 1	1,954	1891	1900	36	----	----	----	Pump installed in 1905, when water stood 45 feet below curb.
No. 2	1,765	----	----	—23	----	----	----	Water level lowered by unknown amount.
Butchers' Association	1.000	----	----	133	*20	----	----	
Chicago, Milwaukee & St. Paul Ry.; round house	1,262	----	----	76	29	----	----	
Julien House	1,660	----	----	109	70	----	----	Original depth, 896 feet; deepened to 1,660 feet in 1898.
Dubuque Packing Co	955	----	----	55	34	----	----	Loss gradual.

Dubuque Brewing & Malting Co.	1,165	----	----	----	¼	----	----	Loss gradual; original depth, 999 feet; repacked, recased, and drilled to present depth; results beneficial.
E. Hemmi	973	1895	----	----	—5	----	----	Stopped flowing in 1902, with use of air lifts on Brewing & Malting Co.'s well.
Key City Gas Co.	1,310	----	----	48	----	----	----	Interference of other wells noted.
Dubuque city well—								
Eighth Avenue	1,310	1888	----	----	10	----	----	Slightly decreased by use of air lift in Eagle Point wells
Sixth Avenue	1,908	1900	----	22	11	----	----	Decreased to one-third normal yield by use of air lift in the Eagle Point wells.
Fort Madison:								
Hospital, Atchison, Topeka & Santa Fe Ry.	764	1892	1902	20	(‡)	----	----	Loss sudden; yield slightly improved by deepening and recasing in 1903.
Keokuk:								
Hubinger wells	2,000	----	1904-1906	----	----	----	----	Loss gradual.
Do	2,230	----	----	----	----	----	----	Ceased to flow in 1908.
Ottumwa:								
Iron works	1,150	1888	----	50	----	----	----	Loss gradual; defective packing.
John Morrell & Co. well—								
No. 1	1,110	1888	1892	36	----	800	207	Loss gradual; well filled with sediment; flow increased by reaming in 1892.
No. 2	1,554	1892	1901	----	----	----	214	Well filled with sediment.
No. 3	1,702	1898	1901	50	----	1,500	241	Do.
No. 4	2,205	1905	1907	----	----	1,450	1,500	Do.
Sabula city well	973	1895	1903	74	64	720	550	Loss gradual.
West Liberty city well:								
No. 1	1,768	1888	----	9	----	120	----	Gradual loss; in 1900 water stood 12 feet below curb and pumping capacity was 75 gallons.
No. 2	1,594	1900	1902	----	----	225	----	Loss gradual; still flows.
Wilton city well	1,360	1891	1898	1½	—20	300	120	Loss gradual; partly reamed in 1900, without effect.

* More or less. ‡ Few inches. † Small.

Abandoned artesian wells.

Location	Depth	Year completed	Year abandoned	Yield: Original	Yield: Present	Remarks
	Feet			*Gallons per min.*	*Gallons per min.*	
Ackley:						
City well	2,030	†1893	†1908	(‡)	----------	
Boone:						
City well—						
No. 1	3,010	1890	1906	70	----------	Abandoned for cheaper supply from shallower wells.
No. 2	2,914	1897	1906	70-80	70-80	Do.
Centerville:						
City well No. 1 in public square	2,495	--------	--------	200	200?	Drilled before waterworks were installed in 1895; never pumped; abandoned in favor of new well at a more convenient location.
Des Moines:						
Greenwood Park well	3,000	1896	1902	----------	----------	Water mains extended into park; no deterioration of yield or head.
Dubuque:						
City well on Eighth Street	1,310	1888	--------	2,500?	100	Original head, 46 feet; head in 1908, 3 feet; loss noted years ago; no repairs ever made.
Fort Madison:						
Brown Paper Co.	689	1888	1902	600	----------	Casing gave way in 1898 and well filled with sand; inside casing was inserted and well was used a few years, when it again caved and was abandoned.
Glenwood:						
Asylum for Feeble-minded	1,910	1897	--------	70	60	Abandoned because of scanty supply and infection with typhoid germs.
Monticello:						
City well	1,198	1875	1900	200	----------	Abandoned because of decreased yield; crooked hole made recasing impossible.
Newton:						
City well—						
No. 1	1,400	1890	--------	----------	----------	
No. 2	705	--------	--------	----------	----------	
Sigourney	1,888	1882	--------	----------	----------	Poor water; never used.
Clinton:						
Dewitt Park	1,675	1890	--------	625	----------	Original head, 44 feet; flow ceased; disconnected from waterworks.

†Before. ‡Ample.

CHAPTER V.

CHEMICAL COMPOSITION OF UNDERGROUND WATERS.

BY W. S. HENDRIXSON.

INTRODUCTION

NATURE OF ANALYSES.

The analytical work of this investigation has been confined to determination of those mineral or inorganic constituents that are commonly found in nearly all ground waters and that have an important bearing on the suitability of the waters for municipal and industrial uses. The following are the substances determined:

Silica (SiO_2).	Potassium (K).
Iron (Fe).	Carbonate radicle (CO_3).
Aluminum (Al),	Bicarbonate radicle (HCO_3).
Calcium (Ca).	Sulphate radicle (SO_4).
Magnesium (Mg).	Nitrate radicle (NO_3).
Sodium (Na).	Chlorine (Cl).

In calculating the averages of the analyses potassium has been included with sodium, as potassium was separately determined in only a few of the waters. In most of the analyses not made by the writer iron and aluminum were determined together as oxides. In a few analyses silica was included with those oxides. It is, therefore, impossible to find true averages of iron and aluminum, and these are omitted from the tables. The proportion of the analyses giving silica separately is large enough to justify including its average in the table, though the average can not be rigidly construed. Where considerable quantities of nitrate were indicated the nitrate radicle NO_3 was determined.

Many deep-well waters contain amounts of ammonia that would be sufficient to cause suspicion of pollution if they were found in waters from shallow wells. The presence of ammonia in water from deep wells is probably due to the reduction of nitrates by pyrite or other reducing substances. Whatever the cause, both the ammonia and the nitrate are to be regarded as due to fermentation long since completed and therefore as without significance from the sanitarian's point of view.

Eleven waters are included for which only total solids were obtainable from the analyses. These are waters analyzed only with a view to their use in boilers, and only the total solids, incrusting matter, and chemicals necessary for softening them are given; they are included in the general tables because there are few available analyses of waters in the regions in which they occur.

The 400 analyses that are tabulated represent waters from all but two of the 99 counties in the state. The majority are analyses of waters from wells of the northeastern part, or deep-well district, of the state. Some counties have no wells of considerable depth which enter sources of water of more than local character. In some this may be due to the absence of easily available sources of large water supplies, as is apparently true in some parts of southern Iowa. In others the existing deep-water resources have not been developed; for example, six counties—Worth, Howard, Chickasaw, Butler, Grundy and Buchanan—all favorably located in the artesian district, have, so far as known, no wells penetrating the lower sandstones. Five others—Mitchell, Floyd, Franklin, Black Hawk and Delaware—have only one such well each. In these counties there are few large towns, and most of the small towns having water systems procure supplies to meet present needs from shallow wells or from streams. As they grow and their demands increase a large development of the deep-water resources may be expected.

STATEMENT OF ANALYTICAL RESULTS.

FORM OF ANALYSES.

In the statements of results of analyses by other chemists the mineral constituents are frequently expressed in the form of salts and oxides. As the oxides of aluminum and iron are commonly weighed together, it is impossible to separate the iron and aluminum in the recalculated analyses and their combined oxides are therefore given in this report unchanged. The same applies to silica when it was weighed with the oxides of aluminum and iron.

Until recently it was customary to represent the results of analyses of water in terms of hypothetical compounds as they were supposed to exist in solution. Many have been the discussions, not to say controversies, as to whether, for example, calcium would combine with the sulphate radicle rather than with chlorine, according to inherent selective affinity. All such discussions have been rendered irrelevant by general acceptance of the ionic theory, for it is now well known that the mineral matter in such dilute solutions as the average well water exists almost entirely as free radicles, with the exception of silica, which is given as SiO_2. There is no longer any scientific reason why the results should be represented as compounds, and there is very little in the way of practical convenience to justify such practice. It is true that if any given water be evaporated to dryness the contained substances separate out as compounds according to the law of least solubility, and in a definite order according to the relative amounts of the substances present, but the order would scarcely be the same for any two waters. The only logical procedure is, therefore, to give the constituents as radicles, though it may be a little confusing to those who are unaccustomed to this mode of expressing results.

In the enumeration of radicles that were determined, two forms of combined carbonic acid have been given. As a matter of fact, Iowa deep-well waters are almost without exception acid to phenolphthalein and contain free carbon dioxide. The carbonate radicle is regarded, therefore, as HCO_3 and is so given in the tabulated results of analyses. It has been thought better in summing up the radicles determined to give the total solid matter as it would be weighed on evaporation to dryness; that is, with the carbonates as normal salts. The change on evaporation is represented by the decomposition of acid calcium carbonate, $Ca(HCO_3)_2 = CaCO_3 + CO_2 + H_2O$. The ratio of $2HCO_3$

to CO_3 is 2.03 to 1, or, with sufficient accuracy, 2 to 1. Therefore, one-half the weight of the bicarbonate radicle, HCO_3, is subtracted from the sum of the radicles as they are in solution, to obtain a figure representing the probable amount of solids left by evaporation to dryness and heating to 180° C., according to common practice.

The amount of mineral matter in solution is given in parts per million instead of in grains per gallon. To avoid any confusion at this point the following considerations may be presented with certain simple rules derived from them for changing data in one system into their equivalents in another:

1. One liter of water weighs 1,000,000 milligrams, and it follows that 1 milligram or 0.001 gram of solids per liter of water is equivalent to one part per million.

2. One grain per United States gallon is equivalent to 17.118 parts per million, or 0.017118 gram per liter.

To change from one system to another, therefore, the appropriate rule may be selected from the following and applied to the data at hand.

To get grains per United States gallon from parts per million, divide by 17.1; or from grams per liter, divide by 0.0171.

To get parts per million from grains per United States gallon, multiply by 17.1; or to get grams per liter from grains per United States gallon, multiply by 0.0171.

RECOMPUTATION OF FORMER ANALYSES.

Though there is at the present time very little scientific justification for representing the mineral matter dissolved in water in terms of compounds, it has been the almost universal custom till very recently. From such theoretical combinations the temporary and permanent hardness of waters have been determined, their power to form boiler scale has been calculated, and the nature and amounts of the agents necessary to soften them have been decided. It is not necessary for any of these purposes to assume the existence of compounds in waters (see p. 161). Many persons, however, prefer to have an analysis of water stated in terms of compounds, and it certainly is necessary in the comparison of the qualities of two waters to have the analyses expressed in the same terms. For these reasons it seems desirable to make certain statements regarding the relations of the two methods of stating results and to give a logarithmic table to facilitate the conversion of the data of one system into those of the other.

In the calculation of the results of analysis to compounds the practice is by no means uniform. Perhaps the most common method is as follows: Granting that the water contains the usual kinds of mineral matter and is acid to phenolphthalein, the bicarbonate radicle is calculated to calcium and magnesium in order till it is exhausted. The remaining calcium and magnesium, or very probably magnesium only, is calculated to sulphate. Any remaining sulphate radicle and also the chlorine are calculated to sodium compounds, and to potassium if that element is separately determined. Silicon, iron, and aluminum are commonly reported as the oxides. The calculation must be varied, of course, in accordance with the water in hand. This statement applies to a typical Iowa water of moderate mineralization.

In order to facilitate recomputation of analyses of that nature, a table of logarithmic factors is given. It contains all the compounds that have been found in converting the data of old analyses for use in this report. Column A contains the logarithms of the chemical factors necessary to find the radicles on the left from their compounds on the right. For example, the factor for computing the amount of calcium in calcium carbonate is 40.1÷100.1, and its logarithm is 0.6027. In column B are the logarithms of the chemical factors plus the logarithm of the factor necessary to convert grains per United States gallon into parts per million. According to a recent determination of the Bureau of Standards, this factor is 17.117967, or, with sufficient accuracy, 17.118, and its logarithm is 0.23345. The logarithm for computing parts per million of calcium from grains per gallon of calcium carbonate is, therefore, 0.8361. As is usual in such logarithmic tables, the characteristics are omitted. It is hardly necessary to state that one may obtain logarithms of compounds corresponding to radicles by subtracting the appropriate logarithmic factor from the logarithms of the weights of the radicles.

Logarithmic factors necessary for recomputing analyses.

Amount of—	In—	Logarithmic Factors		Amount of—	In—	Logarithmic Factors	
		A	B			A	B
Ca	$CaCO_3$	0.6027	0.8361	Cl	$CaCl_2$	0.8053	0.0388
Ca	$CaSO_4$	.4691	.7025	Cl	$MgCl_2$	.8717	.1052
Ca	$Ca(HCO_3)_2$	.3934	.6268	Cl	NaCl	.7825	.0159
Ca	$CaCl_2$	.5577	.7912	Cl	KCl	.6769	.9103
Ca	CaO	.8542	.0876	SO_4	$CaSO_4$	.8485	.0819
Mg	$MgCO_3$	.4605	.69 0	SO_4	$MgSO_4$	.9018	.1353
Mg	$MgSO_4$	.3060	.5394	SO_4	Na_2SO_4	.8298	.0632
Mg	$MgCl_2$	.4077	.6411	SO_4	K_2SO_4	.7411	.9745
Mg	$Mg(HCO_3)_2$	.2213	.4547	SO_4	$BaSO_4$	.6143	.8478
Mg	MgO	.7807	.0142	SO_4	SO_3	.0791	.3126
Mg	$Mg_2P_2O_7$	.3399	.5734	CO_3	$CaCO_3$	.7777	.0112
Na	Na_2CO_3	.6380	.8714	CO_3	$MgCO_3$	.8520	.0855
Na	$NaHCO_3$	.4381	.6716	CO_3	Na_2CO_3	.7524	.9859
Na	Na_2SO_4	.5109	.7444	CO_3	K_2CO_3	.6373	.8708
Na	NaCl	.5955	.8290	CO_3	$FeCO_3$	.7141	.9475
Na	Na_2O	.8706	.1041	CO_3	CO_2	.1347	.3681
K	K_2CO_3	.7529	.9864	NH_4	NH_3	.0248	.2583
K	K_2SO_4	.6523	.8858	NH_4	N	.1091	.3426
K	KCl	.7200	.9534	HCO_3	Na_2CO_3	.9393	.1727
K	K_2O	.9193	.1528	HCO_3	K_2CO_3	.0545	.2879
K	$KHCO_3$	.5921	.8255	HCO_3	$CaCO_3$	.9140	.1474
K	K_2PtCl_6	.2073	.4407	HCO_3	$MgCO_3$	.8397	.0731
Fe	Fe_2O_3	.8449	.0783	HCO_3	$FeCO_3$	.9777	.2111
Fe	$FeCO_3$	.6833	.9168	HCO_3	CO_3	.6918	.9251
Al	Al_2O_3	.7245	.9580				

CHEMICAL COMPOSITION OF WATER BY DISTRICTS

To facilitate the study of well waters in relation to geographic distribution, the state has been subdivided into eight arbitrary districts (see fig. 2), known as the northeast, north-central, northwest, east-central, central, southeast, south-central and southwest districts. The composition of the waters will be discussed according to these districts, the analyses within each being arranged alphabetically by counties. The tables contain both analyses of well waters made originally for this report and those received from other sources.

NORTHEAST AND NORTH-CENTRAL DISTRICTS.

The northeast and north-central districts contain most of the slightly mineralized water of the state. The quality of the waters in the two districts is so nearly the same that both may as well be considered together.

With two exceptions—those of the deep wells at Bancroft and McGregor—the solids of the deep-well waters do not reach 1,000

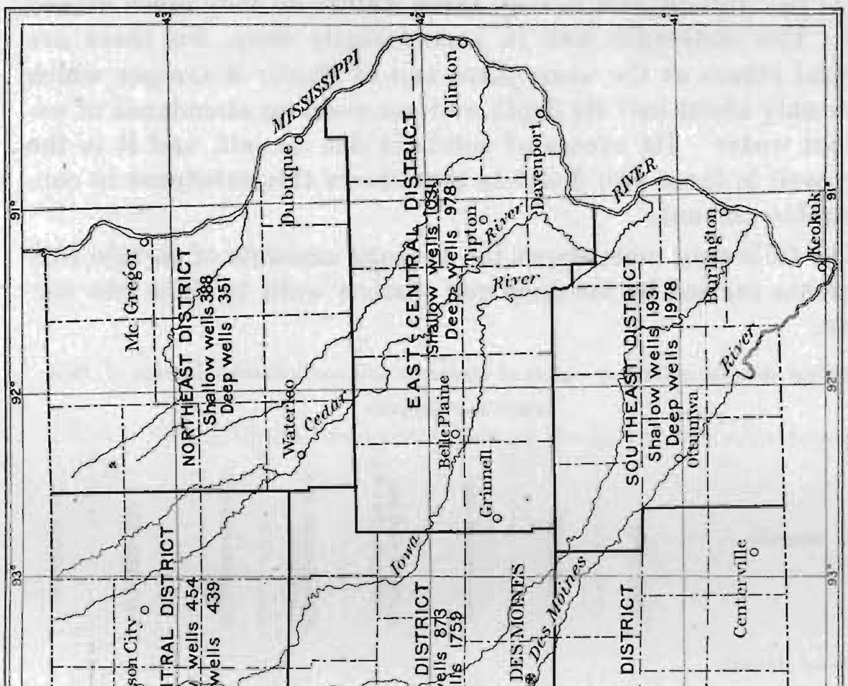


Figure 2—Map showing division of state into districts, and the average mineral content of waters of deep and shallow wells in each district.

parts per million, and in only three waters do they much exceed 500. The McGregor well is unnecessarily deep, for there are several others at the same place and at North McGregor which have only about half its depth and yet yield an abundance of excellent water. Its excess of solids is due to salt, and it is the only well in these two districts that shows this substance in considerable amount.

The following table shows the average amounts of certain constituents carried by the deep and shallow wells in these two sections:

Average mineral content of waters in northeast and north-central districts of Iowa

[Parts per million]

Source	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids a
Northeast District—								
30 deep wells	10	63	31.	28	321	38	24	351
20 shallow wells	15	89	32	16	347	83	12	388
North-Central District—								
7 deep wells	11	87	33	20	328	92	14	439
37 shallow wells	18	99	32	253	418	68	8.8	454

a The sum of the constituents minus one-half the bicarbonate radicle.

The average solids for the deep wells and for the shallow wells of the districts are nearly the same. The best wells of each sort contain about 270 parts per million of mineral matter. The shallow-well waters are as uniformly good as the waters of the deep wells, the only two shallow wells approaching or reaching 1,000 parts of solids being those at Bancroft and at New Hampton. The waters of a few of the best wells of both classes contain about the same amounts of solids as the waters of Des Moines, Iowa, and Cedar rivers, which rise in these districts. The shallower wells, unlike many in the southern and southwestern parts of the state, are not commonly located in the flood plains of rivers. In fact flood plains are less common in this part of the state, the rivers more often flowing between bluffs of considerable height.

With the exception noted at McGregor the waters of the districts are entirely normal—that is, they contain for the most part magnesium, calcium, and bicarbonates, and the harder ones contain notable amounts of sulphates. They are the best boiler waters of the state, as well as the best for general municipal and industrial purposes.

Analyses of water in the northeast district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids a	Name of Chemist
Howard County																	
Cresco	City	400	Galena	20	-----	----	2	115	36	26		315	66	71	46	540	W. S. Hendrixson
Do.	do	200	Devonian (?)	26	-----	----	3	116	29	32		306	80	68	58	565	Do.
Lime Springs	J. W. Davis	166	Devonian limestone	20	-----	----	1	121	49	10		446	10	-----	28	540	Do.
Winneshiek County																	
Calmar	Chicago, Milwaukee & St. Paul Ry. Co.	1,223	St. Lawrence	----	2	----	-----	90	24	1		302	36	-----	2	306	H. E. Smith
Decorah	Union Springs	-----	-----	13	-----	----	.5	78	27	4	1	330	18	-----	4.3	311	W. S. Hendrixson
Ossian	T. V. Gilbert	730	New Richmond	18	-----	----	1	124	36	20		392	73	-----	50	518	Do.
Do.	Chicago, Milwaukee & St. Paul Ry. Co.	155	-----	----	3	----	-----	89	46	2		478	21	-----	2	402	Geo. N. Prentiss
Allamakee County																	
New Albin	Hotel	500	Cambrian sandstone underlying the Dresbach.	7	-----	----	1.3	49	56	6	2.5	390	18	-----	8	343	W. S. Hendrixson
Do.	Creamery	470	do	9	-----	----	.5	48	53	14	2	378	19	-----	6.5	341	Do.
Lansing	City	668	do	9	-----	----	-----	42	17	99	5	284	63	-----	73	450	Do.
Do.	A. C. Doehler	640	do	12	-----	0.3	-----	44	16	95	9	274	59	-----	64	436	Do.
Postville	Chicago, Milwaukee & St. Paul Ry. Co.	80	-----	----	-----	----	1	99	32	7		402	33	-----	4	377	Geo. N. Prentiss
Do.	City	515	Saint Peter	8	-----	----	1	77	41	11	4	402	35	-----	4	382	W. S. Hendrixson
Village Creek	A. C. Doehler	750	Cambrian sandstone underlying the Dresbach.	9	-----	.2	-----	57	23	50	8	274	46	-----	42	372	Do.
Waukon	City	600	do	10	-----	----	2	88	24	5	2	324	30	-----	7	330	Do.

Chickasaw County																	
New Hampton	City	235	Devonian & Maquoketa.	8	----	1	.1	64	27	18	3	289	35	----	5	306	W. S. Hendrixson
Do.	Chicago, Milwaukee & St. Paul Ry. Co.	188	Devonian	----	3	----	----	219	50	24		456	366	----	33	923	Geo. N. Prentiss
Ionia	do	148	----	----	7	----	----	78	26	25		389	28	----	1	364	Do.
Do.	do	155	----	----	3	----	----	81	27	24		393	37	----	1	370	Do.
Bremer County																	
Fairbank	H. Leistikow	118	Drift	8	----	2	.3	70	28	25		406	1	----	2	339	W. S. Hendrixson
Sumner	City	1,740	Saint Lawrence	8	----	1	1	43	20	63	9	353	8	----	4	334	Do.
Waverly	do	1,720	do	6	----	----	2	66	30	32	9	341	56	----	7	379	Do.
Fayette County																	
Fayette	----	----	----	----	----	----	2	66	20	4	2	238	22	----	5	240	W. S. Hendrixson
West Union	City	70	----	----	3	----	----	75	24	11		348	9	----	10	306	Geo. N. Prentiss
Clayton County																	
Elkader	City	186	Saint Peter	8	----	.3	.2	68	28	12		288	57	----	.5	318	H. S. Spaulding
McGregor	do	520	Cambrian sandstone underlying the Dresbach.	7	2	----	----	58	29	47		510	54	----	36	488	J. B. Weems
Do.	City (No. 2)	1,006	do	6	6	----	----	160	20	706		509	465	----	968	2,585	Do.
Do.	City (No. 3)	520	do	9	----	.4	2	89	36	179		345	133	----	246	867	W. S. Hendrixson
North McGregor	City	430	do	10	----	----	3	68	[illegible]	51	4	301	54	----	61	429	Do.
Do.	Chicago, Milwaukee & St. Paul Ry. Co.	480	do	----	----	----	----	67	28	45		309	44	----	59	397	Geo. N. Prentiss
Monona	Wellman	420	Galena	----	2	----	----	101	44	16		371	133	----	19	500	Do.
Do.	City	450	do	14	----	.5	.6	86	42	16		335	86	----	10	423	W. S. Hendrixson
Black Hawk County																	
Hudson	City	158	----	9	----	.1	1	100	27	11	4	206	186	----	3	444	W. S. Hendrixson
Waterloo	Water Co.	1,373	Saint Lawrence	7	----	----	1	78	38	41	5	368	106	----	8	468	Do.
Buchanan County																	
Jesup	City	312	Devonian	14	----	----	3	83	30	9		283	48	----	7	335	W. S. Hendrixson
Delaware County																	
Manchester	U. S. Fish Hatchery (spring).	----	----	10	----	----	1	50	20	5	1	207	11	----	.4	206	W. S. Hendrixson

Analyses of water in the northeast district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Do.	City	1,870	Cambrian sandstone underlying the Dresbach.	33	----	----	2	60	17	6		96	134	----	9	309	Do.
Dubuque County																	
Dubuque	Steam Heat Co.	802	Cambrian sandstone underlying the Dresbach.	----	----	----	----	56	36	2		342	15	----	2	282	
Do.	Butchers' Association.	936	do	----	2	----	----	54	31	2		294	17	----	1	254	C. F. Chandler
Do.	Malting Co.	900	do	----	----	----	----	76	22	14		256	26	----	21	287	Geo. N. Prentiss
Do.	Brewing & Malt Co	1,165	do	8	----	0	1	58	37	7	3	310	20	----	8	297	W. S. Hendrixson
Do.	Eighth Street well, City.	1,200	do	12	----	0	.5	54	32	4	3	284	16	----	5	268	Do.
Do.	J. Cushing's foundry.	965	do	----	----	----	----	52	32	8		310	15	----	4	266	Wahl & Henius
Do.	Brewing & Malt Co	999	do	----	----	----	----	71	21	11		302	16	----	18	287	Do.
Do.	City Gas Co.	1,310	do	5	----	1	1	56	33	4	3	310	12	----	10	280	W. S. Hendrixson
Do.	Chicago, Milwaukee & St. Paul Ry. Co.	937	do	----	1.5	----	----	57	35	5		332	15	----	2	281	Geo. N. Prentiss
Do.	do	1,262	do	----	----	----	----	56	33	9		322	18	----	7	284	Do.
Do.	Bank & Insurance Building.	973	do	5	11	----	----	51	25	21		300	21	----	0	284	J. B. Weems
Do.	City, Eagle Point	1,327	do	5	----	----	1	55	33	2	4	316	13	----	5	276	W. S. Hendrixson
Do.	Linwood cemetery	1,954	Sandstone	14	----	2	3	64	32	3		326	34	----	9	324	Do.
Farley	Chicago, Milwaukee & St. Paul Ry. Co.	100	Niagaran (?)	----	1.2	----	----	85	28	17		260	128	----	10	399	Geo. N. Prentiss
Worthington	Chicago, Milwaukee & St. Paul Ry. Co.	95	----	----	*b* 109	----	----	49	41	9		172	151	----	5	450	F. O. Bunnell

a Sum of constituents minus one-half of bi-carbonate radicle.
b Probably this is mostly suspended clay.

Analyses of water in the north-central district of Iowa.

[Parts per million]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Kossuth County																	
Algona	City	1,050	Oneota	10	----	1	1.5	101	54	41	11	420	205	----	10	647	W. S. Hendrixson
Do.	W. Lacey	227	Cretaceous	14	----	1.6	.6	101	32	44		464	84	----	4	549	H. S. Spaulding
Bancroft	Chicago & North Western Ry. Co.	438	----	3	2	----	----	180	65	93		436	518	----	11	1,090	Geo. M. Davidson
Burt	do	600	----	9	3	----	----	136	32	38		494	129	----	6	600	Do.
Germania	Chicago, Rock Island & Pacific Ry. Co.	235	----	----	5	----	----	105	42	50		454	151	----	6	586	F. O. Bunnell.
Irvington	Chicago & North Western Ry. Co.	178	----	26	----	----	----	96	37	7		632	65	----	10	557	Geo. M. Davidson
Luverne	City	35	Drift	----	14	----	----	112	41	----		366	140	28	----	518	F. O. Bunnell
Winnebago County																	
Forest City	City	300	200 ft. in rock	15	----	----	.2	102	34	19	3	460	40	----	4	447	W. S. Hendrixson
Lake Mills	Minneapolis & St. Louis R. R. Co.	240	Mississippian	22	----	----	----	88	27	15		398	22	----	6	379	Geo. M. Davidson
Do.	Chicago & North Western Ry. Co.	334	Devonian limestone	17	----	----	2.2	87	28	5		406	8	----	1.5	352	Do.
Woden	S. Stenerson	116	----	19	----	3	2	67	24	54		442	31	----	1	422	H. S. Spaulding
Worth County																	
Hanlanton	Chicago & North Western Ry. Co.	260	Devonian limestone	22	3	----	----	73	16	24		277	40	----	23	340	Geo. M. Davidson
Manly	Chicago, Rock Island & Pacific Ry. Co.	320	Devonian	----	3	----	----	71	21	2		246	48	----	15	283	F. O. Bunnell
Northwood	City	87	Devonian limestone	18	----	.3	.5	74	24	8		318	1.5	----	8	293	W. S. Hendrixson

Analyses of water in the north-central district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids a	Name of Chemist
Mitchell County																	
Carpenter	Chicago, Milwaukee & St. Paul Ry. Co.	113	----	----	1.5	----	----	72	26	6		304	35	----	7	299	Geo. N. Prentiss
Osage	City	780	Saint Peter	17	----	----	5	116	25	34	3	314	61	----	42	460	W. S. Hendrixson
Do	---- do	280	Maquoketa	----	----	----	----	150	----	21		357	111	----	8	468	Do.
Riceville	McGue (spring)	----	----	24	----	1	2	84	14	24		142	94	30	31	375	Do.
Hancock County																	
Britt	Chicago, Milwaukee & St. Paul Ry. Co.	533	----	----	2.6	----	----	106	41	2		456	51	----	2.3	433	H. E. Smith
Do	---- do	640	----	----	4	----	----	109	40	19		512	47	----	1.6	477	Do.
Corwith	City	118	Mississippian	21	----	1	4	92	35	101		448	188	----	.5	671	W. S. Hendrixson
Garner	Chicago, Milwaukee & St. Paul Ry. Co.	86	----	----	10	----	----	92	32	15		396	45	----	15	307	Geo. N. Prentiss
Goodell	C. Wesenburg	65	Drift	23	----	2.5	3	82	35	18		469	16	----	.2	414	H. S. Spaulding
Cerro Gordo County																	
Dougherty	Chicago & North Western Ry. Co.	----	Devonian	11	1.5	----	----	62	26	2		240	70	----	3.3	296	Geo. M. Davidson
Mason City	---- do	862	Saint Peter	14	2	----	----	60	20	18		240	57	----	8	299	Do.
Do	---- do	----	---- do	15	4	----	----	59	20	18		242	58	----	7	302	Do.
Do	City (No. 2)	651	Platteville	9	----	.6	1	79	35	12	6	424	9	----	6	370	W. S. Hendrixson
Do	City (No. 3)	651	---- do	9	----	5	1.3	81	34	14	5	423	11	----	5	377	Do.
Do	City (No. 4)	651	---- do	8	----	----	1	83	34	13	6	402	11	----	6	363	Do.
Do	Chicago, Milwaukee & St. Paul Ry. Co.	1,473	Dresbach	----	----	----	----	123	59	32		446	211	----	23	671	Geo. N. Prentiss

Floyd County																	
Charles City	City	1,588	Saint Lawrence	9			1	68	23	16		270	40		3	295	W. S. Hendrixson
Marble Rock	do	154	Devonian limestone	13			1	81	18	15		268	35		4	301	Do.
Nora Springs	Chicago, Milwaukee & St. Paul Ry. Co.	100						72	28	12		384	0		3	307	Geo. N. Prentiss
Humboldt County																	
Livermore	City	135	Drift	28		.5	1	110	34	40	6	444	97		4	542	W. S. Hendrixson
Renwick	Chicago & North Western Ry. Co.	81	do		12			108	41	48		523	96		5	571	Geo. M. Davidson
Wright County																	
Belmond	F. Luick	55	Drift	19		3	1	89	28	20		456			1.6	390	W. S. Hendrixson
Clarion	J. Wilson	273	Mississippian	19		2	2	104	31	13		468	17		13	435	H. S. Spaulding
Eagle Grove	Chicago & North Western Ry. Co.	72	Drift		6			114	46	37		568	70		7	564	Geo. M. Davidson
Do.	do	59	do		28			97	39	18		486	34		3	462	Do.
Do.	Dr. McGrath	115	Mississippian	18		1	1	99	31	11		466	20		6.5	420	W. S. Hendrixson
Clarion	City	283	do	18		.4	2.4	96	26	15		440	23		6	407	Do.
Franklin County																	
Hampton	City	1,708	Jordan	13		1.4	2	81	33	21	8	364	59		5	405	W. S. Hendrixson
Latimer	do	150	Mississippian	20		2	3	90	25	21		442	24		6	412	Do.
Butler County																	
Dumont	Chicago & North Western Ry. Co.	14	Alluvium (?)	19	2			152	43	55		548	100		85	730	Geo. M. Davidson

[a] Sum of constituents minus one-half of the bicarbonate radicle.

CHEMICAL COMPOSITION OF WATERS OF THE NORTHWEST DISTRICT.

Hard waters abound in Kossuth and Humboldt counties in the western part of the north-central district of the state, and in Emmet, Palo Alto, Pocahontas and Calhoun counties in the eastern part of the northwest district. Hard waters are, in fact, the rule throughout the northwest district, the average in total solids for all deep wells within the district being 1,425 parts, and for shallow wells 857 parts per million, as indicated in the following table:

Average mineral content of waters in the northwest district of Iowa.

(Parts per million.)

Source	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids [a]
9 deep wells	16	210	67	181	373	719	10	1,425
60 shallow wells	24	160	48	60	420	321	62	857

[a] Sum of the constituents minus one-half the bicarbonate radicle.

The deep wells, unlike those of the northeast and north-central districts, contain hard waters as the rule and soft waters as the rare exception. The only deep waters containing less than 1,000 parts per million of solids are those at Emmetsburg, in Palo Alto county, and at Manson, in Calhoun county. The former belongs to the class of those considered in the northeast and north-central districts, for it contains only 410 parts of solids. The well is in a location where the Cretaceous forms the surface rock. The shallow wells in the county yield hard water, and the Emmetsburg well is probably one in which the casing was very successfully done, the upper hard waters having been effectively excluded. The well at Manson is the only deep well in the state whose water was found to contain normal carbonates; the magnesium and calcium in it are very low, the solids being mostly alkaline chlorides and sulphates. It may be questioned whether its comparatively soft water and its alkalinity may not be due to contamination by surface water owing to faulty casing.

There are few deep wells in the northwest district. Out course, possible that future borings may develop the fact that good deep well water may obtain in this section.

The waters from shallow wells show a very great variation in quality, ranging from those comparable with the best well waters of the northeast district to those containing more than 2,000 parts of solids per million, as in O'Brien county. The wells in the river bottoms, such as those at Sioux City, supply waters almost uniformly good, but the deeper drift wells usually contain hard water. Of the wells which do not enter rock and which supply soft water a large proportion are known to derive their water from river alluvium. All but two of the remaining wells of this class are located near rivers and may get their water in part or wholly from the same source. It may, therefore, fairly be questioned whether any considerable number of wells of this district supply slightly mineralized waters wholly from the drift. Aside from the two deep wells already discussed the well of Henry Steinecke, of Aurelia, which is supposed to enter the Dakota sandstone, is the only one in the district so far as investigated that enters rock and supplies comparatively soft water.

Detailed analyses follow.

Analyses of water in the northwest district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Lyon County		Feet															
Rock Rapids	City	25	Alluvium	25	------	1	1	133	41	20		380	186	-----	16	613	W. S. Hendrixson
Doon	do	30	do	28	5	----	-----	126	38	9		306	208	-----	13	580	Geo. M. Davidson
Osceola County																	
Sibley	Chicago, Rock Island & Pacific Ry. Co.	408		----	------	----	-----	288	62	(*b*)		460	569	-----	-----	1,752	F. O. Bunnell
Dickinson County																	
Lake Park	City	98	Drift	32	------	7	5	316	105	32		513	833	-----	4	1,590	H. S. Spaulding
Montgomery	G. R. Badgerow (spring)	------		26	------	2	2	84	26	6		386	7	-----	3	349	W. S. Hendrixson
Spirit Lake	City	100	Drift	27	------	2	1	213	52	52		463	433	-----	20	1,031	Do.
Emmet County																	
Gridley	Chicago & North Western Ry. Co.	430		26	1	----	-----	151	52	32		382	317	-----	6	776	Geo. M. Davidson
Halfa	Farm well	149		28	2	----	-----	117	37	18		534	35	-----	2	506	Do.
Maple Hill	do	455		18	3	----	-----	186	56	65		390	491	-----	2	1,016	Do.
Sioux County																	
Hull	City	1,256	Algonkian	18	------	6	5	322	124	192	23	384	1,380	-----	33	2,295	W. S. Hendrixson
Orange City	do	24	Drift	17	------	----	.5	122	66	22		373	78	64	61	617	Do.
O'Brien County																	
Hartley	do	205	do	----	30	----	-----	335	149	304		506	1,522	-----	33	2,626	F. O. Bunnell
Primghar	J. J. Shonts	372	do	29	------	11	7	375	156	51		570	1,199	-----	7	2,120	W. S. Hendrixson

Sanborn	City	40	do		3			72	21	17	47	245		6	387	Geo. N. Prentiss
Do.	Chicago, Milwaukee & St. Paul Ry. Co.	1,250	Cambrian					353	114	182	458	1,282		26	2,186	H. E. Smith
Sheldon	do	300	Drift		22			238	38	126	567	530		7	1,244	Geo. N. Prentiss
Clay County																
Bridgewater	Mill	250	do		5			154	46	134	440	461		12	1,032	Do.
Peterson	Chicago & North Western Ry. Co.	2(	do	35	3			181	63	28	542	247		43	871	Geo. M. Davidson
Spencer	City	10	Alluvium	25			3	105	22	19	242	161		11	467	W. S. Hendrixson
Palo Alto County																
Ayrshire	do	385	Dakota	24		2.4	2.6	264	83	114	414	852		5	1,554	Do.
Emmetsburg	Chicago, Milwaukee & St. Paul Ry. Co.	874	Saint Peter		9			96	32	17	444	29		5	410	H. E. Smith
Mallard	City	1,100	do	13		10	8	171	55	69	582	386		10	1,013	W. S. Hendrixson
West Bend	do	381	Mississippian	6				174	40	69	672	171		6	802	J. B. Weems
Plymouth County																
Le Mars	Chicago & North Western Ry. Co.	70	Drift	21	8			123	39	18	404	127		28	566	Geo. M. Davidson
Ellendale		202			23			112	38	48	472	43		74	574	F. O. Bunnell
Cherokee County																
Aurelia	H. Steinecke	300	Dakota	34		.3	.8	82	24	18	330	56		1	381	W. S. Hendrixson
Cherokee	State Hospital	1,126	Saint Peter	13		8	1	270	53	258	306	651		20	1,378	Do.
Do.	do	242	Dakota	24		2	1	161	45	68	368	398		4	887	H. S. Spaulding
Marcus	Larson Bros.	400	do	45		1	1	303	73	221	368	1,163		12	2,003	W. S. Hendrixson
Do.	G. Arnold	400	do	16		5	.5	287	77	187	383	1,080		17	1,861	Do.
Buena Vista County																
Alta	City			28		.3	.2	314	97	77	370	693	40	134	1,546	Do.
Albert City	Chicago, Milwaukee & St. Paul Ry. Co.	372						204	76	(c)	472	409			1,302	Geo. N. Prentiss
Marathon	Hawks	83	Drift					250	105	11	820	203		128	1,107	Do.
Pocahontas County																
			Dakota	33		6	4	171	92							
Fonda	City	331								65	518	475		6	1,111	W. S. Hendrixson
Laurens	Chicago, Rock Island & Pacific Ry. Co.	570			9			206	57	102	464	509		15	1,130	F. O. Bunnell
Rolfe	City	108	Saint Louis	28		2	2	176	10	34	522	145		7	665	W. S. Hendrixson

Analyses of water in the northwest district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Woodbury County		Feet															
Luton	Chicago, Milwaukee & St. Paul Ry. Co.	85		----	13	----	----	92	33	13		431	24	----	1	393	Geo. N. Prentiss
Sioux City	Starch works	[illegible]	Cretaceous	----	4	----	----	124	35	32		374	200	----	3	585	Do.
Do.	Cudahy Packing Works	355	do	17	4	----	----	312	30	12		471	93	----	10	713	Geo. M. Davidson
Do.	Water Co.	2,011	Algonkian	16	----	----	6	226	73	222		406	859	----	84	1,689	J. B. Weems
Do.	(*d*)	50–80	Alluvium	28	2	----	----	91	30	14		416	80	----	6	409	Geo. M. Davidson
Do.	City	104	do	----	3	----	----	88	22	16		279	101	----	3	372	Geo. N. Prentiss
Ida County																	
Battle Creek	A. Harper	217	Sand	22	----	.4	1.2	84	21	18		368	41	----	5	376	W. S. Hendrixson
Galva	Chicago & North Western Ry. Co.	60	do	27	----	----	6	161	32	23		392	232	----	12	689	Geo. M. Davidson
Holstein	City	2,004	Dresbach	28	----	4	2	243	66	115	10	348	782	----	12	1,436	W. S. Hendrixson
Sac County																	
Nemaha	Creamery	400	Drift	14	----	8	1	88	35	171		[illegible]	419	----	14	946	Do.
Sac City	City	40	do	19	----	----	----	98	43	29			[illegible]	----	16	490	Geo. M. Davidson
Do.	Canning Works	378	do	14	2	----	----	192	60	257			874	----	7	1,623	Do.
Schaller	C. O. Porter	432	do	18	----	2	5	272	88	182		[illegible]	[illegible]	45	13	1,793	W. S. Hendrixson
Wall Lake	City	25	do	20	----	----	1	90	28	7		[illegible]	[illegible]	----	4	382	Do.
Calhoun County																	
Lake City	Chicago & North Western Ry. Co.	210	do	18	1	----	----	164	33	86		476	320	----	6	866	Geo. M. Davidson
Do.	do	69	do	----	5	----	----	106	[illegible]	25		535	47	----	3	495	Do.
Lohrville	City	130	Sand	19	----	2.5	.5	214	72	264		514	493	----	18	1,355	W. S. Hendrixson

Manson	do	1,260	Galena (?)	10	----	.2	.8	16	1	221		c 4	162	----	206	651	Do.
Pomeroy	do	149	Sand	39	----	1.3	3	168	61	138	4	524	522	----	7	1,205	H. S. Spaulding
Rockwell City	do	967	----	18	----	2.5	2.4	118	53	45		440	215	----	7	680	W. S. Hendrixson
Monona County																	
Mapleton	Chicago, Milwaukee & St. Paul Ry. Co.	59	Alluvium	----	28	----	----	91	34	8		366	61	----	11	416	Geo. N. Prentiss
Onawa	City	863	----	10	----	1	1.5	244	81	184	33	207	943	----	166	1,767	W. S. Hendrixson
Do.	Chicago & North Western Ry. Co.	78	Drift	25	2	----	----	141	47	17		494	144	----	24	647	Geo. M. Davidson
Soldier	do	30	----	18	5	----	----	60	19	3		268	9	----	2	250	Do.
Crawford County																	
Denison	City	25	Alluvium	31	----	.5	2	91	24	12		270	72	----	18	385	W. S. Hendrixson
Charter Oak	City (f)	26	do	----	6	----	----	85	24	16		400	7	----	5	343	Geo. N. Prentiss
Manilla	City	68	Drift	25	----	2.5	2	90	23	15	1	361	20	----	5	364	W. S. Hendrixson
Ricketts	Chicago & North Western Ry. Co.	34	Alluvium	22	1	----	----	94	29	13		302	119	----	5	434	Geo. M. Davidson
Carroll County																	
Carroll	City	120	Drift	21	1	----	----	95	29	16		374	61	----	9	419	W. S. Hendrixson
Do.	Chicago & North Western Ry. Co.	153	do	27	2	----	----	99	29	20		410	62	----	4	448	Geo. M. Davidson
Glidden	City	122	do	21	----	.5	3	123	36	22		337	70	----	4	454	W S. Hendrixson
Lanesboro	Lane	128	----	----	----	----	----	88	28	28		442	19	----	----	384	W. H. Chadbourn
Manning	Chicago & North Western Ry. Co.	20	----	18	1	----	----	101	31	17		318	110	----	26	463	Geo. M. Davidson

a Sum of the constituents minus one-half the bicarbonate radicle.
b Alkali, chlorides and sulphates, 603 parts.
c Alkali, sulphates, and chlorides, 377 parts.
d 123 drive wells.
e Carbonate radicle (CO_3), 38 parts.
f 11 city wells.

CHEMICAL COMPOSITION OF WATERS OF THE EAST-CENTRAL DISTRICT.

The following table of averages is made from analyses showing great diversity in the quality of the waters, in both the deep and the shallow wells, of the east-central district.

Average mineral content of the waters of the east-central district of Iowa.

[Parts per million.]

Source	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids *a*
35 deep wells	10	103	47	182	326	425	83	978
45 shallow wells	14	177	58	90	364	495	25	1,031

a Sum of the constituents minus one-half the bicarbonate radicle.

On the Mississippi at Clinton are many deep wells whose waters are among the best, having only 100 parts of solids more than the well waters at Dubuque. The Clinton waters are really not harder than those at Dubuque, as hardness is ordinarily understood and determined by the soap test—that is, their calcium and magnesium are no more abundant and their excess of solids is made up of alkalies, chlorides and sulphates. The same is practically true of the wells at Davenport, where the waters carry more than 1,000 parts per million of solids, but the calcium and magnesium are actually smaller in amount, the excess over Dubuque being due to the alkalies. The tendency is for the amounts of sodium and potassium in well waters to increase down the river until at Keokuk these radicles amount to about 900 parts. The deep wells at Tipton, in Cedar county, at Vinton, in Benton county, and at Cedar Rapids, Monticello, and Green Island all yield good water. Vinton may be regarded as about the western limit of the area of good water, since the well at that place yields only lightly mineralized water, whereas those farther south at West Liberty and Wilton contain more than 1,000 parts of solids. The line from Vinton through Iowa City to Davenport forms the southwestern boundary of the district of good deep well water in the district. This line coincides in a general way with the median line of the strip of the Devonian rocks whose trend is from northwest to southeast. (See Pls. I, IV.) Southwest of this line all deep-well waters are comparatively highly mineralized, as shown by the analyses from Amana, Homestead, Wilton, West Liberty, and Grinnell. The average solids in deep-well water at Grinnell since the first well was drilled 15 years ago have been about 1,200 parts per million, but well No. 2 at its best contained only 881 parts. It is probably true generally that wells penetrating thick layers of Carboniferous and Devonian formations, as at Grinnell, take from them more or less of their waters, owing to imperfect casings, and the waters yielded by such wells rarely or never show the quality of the water of the deeper sandstone formations which they penetrate.

The waters of the shallow wells of the east-central district show great variation. Generally speaking, those in the eastern and especially the northeastern portion have low total solids and are to be rated with those of the wells of the northeast district in regard to quality; probably they draw their water from drift having the same origin and the same general character. On the other hand, wells in the western part of the district have, as a rule, hard waters. A well-marked area of hard waters from wells in the drift and upper strata may be considered to center not far from Tama, in Tama county. All waters in Tama county, so far as investigated, are hard with the exception of that from the very shallow city well at Tama, which probably derives its water from the underflow of Iowa river. The area includes numerous wells, many of them flowing, in the noted Belle Plaine neighborhood. As far south and east as Marengo flowing wells deliver very hard water. It is possible that the same area may extend as far as Amana and Homestead and may account for the hardness of the waters in the deep wells at those places. Farther south, at Williamsburg, the drift wells yield waters that are comparatively little mineralized. All wells investigated in Poweshiek county, save that at Brooklyn, yield hard waters. It is probably true that the Brooklyn well is not exclusively a drift well but obtains its water in part from river alluvium.

Analyses of water in the east-central district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Tama County		Feet															
Buckingham	Chicago & North Western Ry. Co.	318		33	1			215	61	118		336	704		3	1,318	Geo. M. Davidson
Chelsea	City	100	Drift	15		5	2	489	204	38		240	1,923		7	2,803	H. S. Spaulding
Clutier	F. Kiezeks	210	Mississippian	14		1.5	3	97	47	164		160	636		9	1,051	Do.
Do	Chicago & North Western Ry. Co.	225	do	11	2			215	92	157		344	917		7	1,573	Geo. M. Davidson
Gladbrook	A. Angel	310	do	15		3	4.4	138	57	61		320	481		6	925	E. B. Benger
Tama	Mrs. C. A. Huber	861	Silurian	11		3	1	471	200	1,016		260	3,572		128	5,532	Do.
Toledo	County Home	545	Devonian	11		3	2	275	144	64		251	1,119		7	1,753	W. S. Hendrixson
Traer	City	249	Mississippian	12		2	0	132	51	101		252	362		7	793	E. B. Benger
Vining	do	235	do		3			348	135	46		263	1,244		7	1,914	Geo. N. Prentiss
Tama	do	23		19	2			82	19	12		296	32		18	333	Geo. M. Davidson
Benton County																	
Belle Plaine	City	1,520	Prairie du Chien	22		1	3	346	135	72	11	268	1,247		9	1,980	W. S. Hendrixson
Do	(*b*)	193	Drift	2		6	0	504	201	38		334	1,814		6	3,738	L. W. Andrews
Keystone	City	1,402						106	40			524				408	Geo. N. Prentiss
Vinton	W. H. Whipple	2,000	Dresbach (?)	10		3	2	79	44	82		312	248		1	625	W. S. Hendrixson
Do	City	198	Jordan	7			1	72	38	66	12	353	179		10	561	Do.
Van Horne	Van Dusen's spring							58	18	2		240	21		3	222	Geo. N. Prentiss
Do	Creamery	365						140	59	172		481	542		4	1,157	Do.
Do	City	130		1				570	77	173		1,836	580		3	2,322	Do.
Do	John Hollar	795	Maquoketa	2.2	2.6			168	107	216		385	945		11	1,669	Fidelity and Casualty Co.
Linn County																	
Cedar Rapids	Young Men's Christian Association	1,450	Jordan	3			0	70	81	91		340	207		.4	572	J. B. Weems
Do	East City	1,450	do	8			1	73	36	83		312	315		14	586	W. S. Hendrixson
Do	West City	1,450	do	9	.3		.2	75	39	85	11	318	219		14	611	Do.

Covington	A. Laing	241	Silurian		1.4			155	56	18		452	264		2	722	Geo. N. Prentiss
Lisbon	Chicago & North Western Ry. Co.	260	Niagaran	22	2.5			73	40	6		332	74		9	392	Geo. M. Davidson
Do.	Chicago & North Western Ry. Co. at station.	26		7	2			157	68	11		334	379		17	808	Do.
Marion	Chicago, Milwaukee & St. Paul Ry. Co.	100						71	21	4		330	3		1	265	Geo. N. Prentiss
Mount Vernon	City	330	Niagaran	21	8			58	30	9		298	7		14	286	Nicholas Knight
Jones County																	
Anamosa	State Penitentiary	2,200	Cambrian sandstones underlying Dresbach	10			1	92	36	11	3	362	58		15	417	W. S. Hendrixson
Monticello	City	1,198	Jordan	23	25			98	5	39		392	17		6	409	J. B. Weems
Do.	do	319	Maquoketa	13		.5	1	82	29	9		360	22		8	344	W. S. Hendrixson
Morley	Chicago & North Western Ry. Co.	214	Niagaran		4			72	25	6		346	10		2	292	Geo. M. Davidson
Onslow	do	214	do	15	14			91	33	7		412	27		6	399	Do.
Jackson County																	
Green Island	Chicago, Milwaukee & St. Paul Ry. Co.	323	Saint Peter					52	36	2		320	17		1	265	Geo. N. Prentiss
Maquoketa	Chicago & North Western Ry. Co.	185		18	1			100	46	96		510	33		134	683	Geo. M. Davidson
Preston	City	108			.7			70	12	38		339	27		1	318	Geo. N. Prentiss
Sabula	do	973	Oneota	8	6			54	32	14		337	21		0	298	J. B. Weems
Poweshiek County																	
Brooklyn	City	180		13		.6	.5	47	18	120	4	432	87		3	509	W. S. Hendrixson
Grinnell	City (1)	2,002	New Richmond *c*	16		2	4	260	117	192	9	336	1,274		20	2,062	Do.
Do.	City (2)	2,002	do	11		.4	1	103	41	142	15	358	368		21	881	Do.
Do.	City (3)	2,020	do	13		2	.3	131	48	133		324	574		34	1,147	Do.
Do.	John Goodfellow *a*	268	Carboniferous	11			2	250	93	263		116	1,342		10	2,029	Do.
Do.	Creamery	400	Mississippian	21		3	2	216	142	145		368	1,429		13	2,155	Do.
Do.	H. M. Bray	635	Devonian (?)	11		3	5	337	134	1,483		330	3,424		470	6,032	Do.
Montezuma	City	180		14		2	1	360	168	97	13	328	1,462		6	2,287	Do.
Do.	Farwell estate	2,800?		13		3	2	175	92	279	9	341	1,052		40	1,835	Do.
Deep River	Chicago & North Western Ry. Co.	40		20	1			120	40	41		406	193		12	630	Geo. M. Davidson
Iowa County																	
Amana	Amana Society	1,640	Prairie du Chien	5	6.4			104	42	181		320	517		18	1,033	J. B. Weems
South Amana	do			9			2	354	148	133	15	258	1,510		14	2,314	W. S. Hendrixson
Homestead	do	2,224	Dresbach	17	10			101	88	186		249	512		33	1,016	J. B. Weems
Marengo	A. M. Henderson			8		3	3	407	170	125		257	1,668		13	2,525	W. S. Hendrixson
Do.	City				14			75	18			224	75			322	F. O. Bunnell
Williamsburg	Hughes well	195			10			47	15	*e* 97		473	0		2	407	Geo. N. Prentiss
Do.	City	95			1			57	19	106		536	2		6	459	Do.

Analyses of water in the east-central district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Johnson County		Feet															
Solon	Chicago, Rock Island & Pacific Ry. Co.	80		----	61	----	----	119	12	45		214	223	----	24	591	F. O. Bunnell
Cedar County																	
Lowden	Chicago & North Western Ry. Co.	75		15	1	----	----	70	21	3		308	6	----	4	274	Geo. M. Davidson
Stanwood	do	110		8	2	----	----	71	[illegible]	11		368	3	----	0	305	Do.
Tipton	City	2,696	Cambrian or Algonkian.	15	----	----	1	82	26	12	1	379	4	----	2	332	W. S. Hendrixson
Clinton County																	
Browns	Chicago, Milwaukee & St. Paul Ry. Co.	[illegible]		----	----	----	----	65	34	1		364	0	----	2	284	Geo. N. Prentiss
Clinton	Chicago & North Western Ry. Co.	1,125	Jordan	8	2	----	----	54	23	123		292	110	----	96	562	Geo. M. Davidson
Do	Clinton Brewing Co.	1,620	Cambrian sandstones underlying Dresbach	16	----	----	2	70	26	39		312	41	----	25	375	W. S. Hendrixson
Do	National Papier Mache Co.	1,06[illegible]	Oneota	9	----	2	1	60	21	96		306	63	----	54	451	Do.
Do	Chicago & North Western Ry. Co. (old round house)	1,159	Jordan	[illegible]	[illegible]	----	----	56	20	62		272	69	----	42	400	Geo. M. Davidson
Do	Clinton Gas Co.	1,085	Oneota	11	----	----	2	[illegible]	22	85	9	318	54	----	44	436	W. S. Hendrixson
Do	4 city wells	1,763 1,075–	Jordan to Dresbach.	8	----	[illegible]	1	[illegible]	26	46	10	308	47	----	37	395	Do.
Clinton	Clinton Sugar Refining Co.	1,226	Jordan	[illegible]	1	----	----	62	25	56		288	69	----	55	420	A. P. Bryant

Do.	Iten & Sons	1,180	do	2	1	----	----	44	41	24		246	73	----	32	340	Do.
Dewitt	Chicago & North Western Ry. Co.	267		8	1	----	----	90	43	15		372	90	----	20	453	Geo. M. Davidson
Do.	do	165		11	2	----	----	85	30	30		412	65	----	23	462	Do.
Grand Mound	City	100	Silurian	12	----	1	1	60	31	5		305	1	----	1	364	W. S. Hendrixson
Do.	Geo. Jordan	144	do	17	----	1	3	64	23	6		317	1	----	2	275	Do.
Lyons	Chicago, Milwaukee & St. Paul Ry. Co.	----		----	----	----	----	64	26	74		282	74	----	85	464	Wahl & Henius
Scott County																	
Davenport	Davenport Malting Co.	1,976	Saint Peter	----	----	----	----		23	371		166	230	----	330	1,132	Geo. N. Prentiss
Do.	People's Gas Co.	1,200	Prairie du Chien	9	----	4	2	45	18	340		288	249	----	320	1,132	W. S. Hendrixson
Do.	Wilts Bottling Works.	780	Galena and Platteville	7	----	4	----	14	8	429		410	271	----	272	1,210	E. T. Burghausen
Do.	Crystal Ice Co.	1,067	Saint Peter	9	----	2	----	20	5	407		286	275	----	273	1,134	J. B. Weems
Do.	Independent Baking Co.	900		8	2	----	----	17	8	452		430	340	----	244	1,286	E. G. Smith
Do.	Bettendorf Metal Wheel Co.	1,650		11	2	----	----	60	36	256		462	206	----	337	1,233	Do.
Eldridge	Chicago, Milwaukee & St. Paul Ry. Co.	182		----	8	----	----	105	41	16		270	195	----	31	529	Geo. N. Prentiss
Walcott	City	143	Drift	18	----	4	3	82	27	10		406	[illegible]	----	2	351	W. S. Hendrixson
Muscatine County																	
West Liberty	City	1,768		8	----	----	2	82	33	225	15	280	457	----	102	1,064	W. S. Hendrixson
Wilton	do	1,360		8	----	----	2	72	34	274	16	292	397	----	100	1,146	Do.

a Sum of the constituents minus one-half the bicarbonate radicle.
b Jumbo.
c Water probably from Carboniferous.
d 3 miles northeast of town.
e Alkali, sulphates and chlorides, 28 parts.

CHEMICAL COMPOSITION OF WATERS OF THE CENTRAL DISTRICT.

The central district of Iowa contains few deep wells, but they are fairly well distributed. The northeastern part falls within the territory of good deep wells. It is an interesting fact that in Hamilton, Hardin, Grundy and Marshall, the four counties nearest the northeast corner of the district, in all of which the artesian possibilities are probably best, there is only one deep well, except the deep gas boring at Webster City, which probably receives water from all horizons and therefore can not be used for purposes of prognostication.

The one deep well is at Ackley, in Hardin county. Its water contains 605 parts of solids per million and is the best deep-well water in the district, if judged by total solids alone. Fort Dodge has the next best deep well in the order of solids, but not in the order of softness of water. Though the well at Ames, in Story county, and at Jefferson, in Greene county, supply waters containing more than 1,100 parts of solids, these waters are as low in calcium and magnesium as the waters from the deep wells at Davenport, and, as at Davenport, by far the larger portion of their solids consists of sodium chloride and sulphates. The waters of all other deep wells of the district contain large amounts of solids and are also very hard, as rated by their content of calcium and magnesium.

The average mineral matter in the waters of the shallow wells of the central district is about half that in the deep-well waters, the ratio being 873 to 1,759. The waters of the shallow wells are not excessively hard save in Marshall and Polk counties and in the region immediately surrounding Colfax in Jasper county. There is a rather close analogy between the mineral matter of the Colfax waters and that of the waters of shallow wells at Des Moines, and the wells at both places apparently draw their waters from the same source, the Upper Carboniferous or Pennsylvanian. The shallow-well waters of Webster and Hamilton counties are moderately hard. All other counties of the district show shallow-well waters which could, at no great disadvantage, be compared with the waters of shallow wells in the eastern part of the state.

Average mineral content of waters of the central district of Iowa

[Parts per million.]

Source	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids *a*
10 deep wells	14	174	62	286	262	947	19	1,759
69 shallow wells	23	124	44	125	446	344	88	873

a Sum of constituents minus one-half the bicarbonate radicle.

The average total solids for the deep wells of the district is 1,759; they vary all the way from the 605 parts of solids at Ackley to the 4,369 parts in the deep well at Newton, which is now abandoned. Newton now draws its water supply from driven wells in the valley of South Skunk river.

It is very probable that the four northeastern counties of the district should be included with those of the northeast district. They have no deep wells but from their location should have good deep artesian possibilities, though, of course, as the four counties lie farther to the south and west, water of the same degree of freedom from mineral matter could not be expected.

Analyses of water in the central district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Webster County		Feet															
Dayton	City	65-95	Drift	15	1	----	----	69	46	65		268	255	---	7	592	Geo. M. Davidson
Do	do	688	Kinderhook	27	----	2	0.6	85	41	70		366	205	---	10	624	W. S. Hendrixson
Do	Chicago & North Western Ry. Co.	92	Drift	----	9	----	----	177	51	94		682	193	---	3	818	Geo. M. Davidson
Do	do	91	do	21	3	----	----	91	31	111		442	142	---	5	625	Do.
Fort Dodge	City (new well)	1,827	Jordan	12	----	1	1	114	40	145		419	205	---	144	867	W. S. Hendrixson
Do	County Farm	366	Mississippian	9	----	----	1	287	77	67		432	797	---	24	1,508	Do.
Do	City	129	Rock	13	----	.3	1	117	42	53		454	137	---	4	574	Do.
Gowrie	do	620	Devonian	9	----	----	1.3	103	46	66		421	206	---	10	652	Geo. M. Davidson
Do	Chicago & North Western Ry. Co.	400	Carboniferous	----	14	----	----	190	69	117		919	231	---	10	1,093	Do.
Harcourt	do	63	Drift	26	2	----	----	132	45	32		478	134	---	33	643	Do.
Hamilton County																	
Duncombe	John Mahoney	177	Drift	25	----	12	----	128	44	78		630	128	---	2	732	W. S. Hendrixson
Ellsworth	W. H. Brinton	91	do	14	----	5	1	59	28	46	4	440	0	---	.4	377	H. S. Spaulding
Jewell	City	160	Des Moines	30	----	8	5	93	30	73		512	1	---	20	476	W. S. Hendrixson
Stanhope	Ole Satre	328	Carboniferous	21	----	3	.7	106	39	90		473	54	---	4	563	E. B. Benger
Rowland	W. E. Waugh	108	Drift	16	----	----	1	60	26	23		352	0	---	.5	301	H. S. Spaulding
Stratford	Chicago & North Western Ry. Co.	440	Carboniferous	7	----	----	1	125	57	89		329	433	---	16	892	Geo. M. Davidson
Do	Creamery	520	do (?)	7	----	----	1	123	63	138		606	332	---	10	977	Do.
Webster City	Gas Company	1,250	Galena	33	----	----	----	176	27	112		297	515	---	10	1,021.5	J. B. Weems
Do	City (several wells)	90-100	Drift	17	----	----	3	103	52	22		467	137	---	11	588	W. S. Hendrixson
Hardin County																	
Ackley	Mrs. John Carroll	----	Mississippian	24	----	3	1	72	25	19		402	0	---	1	346	H. S. Spaulding
Do	City	2,032	Jordan	7	----	0	2.5	84	33	75	20	372	183	---	15	605	W. S. Hendrixson
Eldora	do	200	Des Moines	10	----	1	.2	55	24	14	3	300	0	---	2	259	Do.

Do	Boys' Home	250	do	14			2	61	25	16		330	1		3	287	Do.
Hubbard	City	325	do	128		4	14	47	20	21		297	1		3	386	Do.
Do	Chicago & North Western Ry. Co.	84	Drift	28	2			90	31	16		428	33			414	Geo. M. Davidson
Iowa Falls	City	240	Kinderhook	13		.6	1.4	77	29	9	2	383	2		5	329	W. S. Hendrixson
Grundy County																	
Dike	Chicago & North Western Ry. Co.	358	Mississippian	18	5			67	25	20		322	40		3	339	Geo. M. Davidson
Grundy Center	City	469	Devonian	9		.4	1	155	71	21		283	447		4	850	W. S. Hendrixson
Holland	L. Beenken	344	Mississippian (?)	15		.4	2	56	33	97		457	26		2	460	Do.
Reinbeck	City	339	do	40		1	1	109	41	24		288	270		5	635	Do.
Greene County																	
Cooper	Chicago, Milwaukee & St. Paul Ry. Co.	190			6			127	39	31		466	130		13	579	Geo. N. Prentiss
Grand Junction	Chicago & North Western Ry. Co.	300	Des Moines	9	1			70	26	67		502	0		6	430	Geo. M. Davidson
Do	Chicago & North Western Ry. Co.	70	Drift	17				113	38	28		470	93		7	531	Do.
Jefferson	City	2,000	Below Saint Peter	13		5		39	16	331		198	536		114	1,153	A. A. Bennett
Do	Chicago & North Western Ry. Co.	100	Drift	15				160	45	17		620	94		7	648	Geo. M. Davidson
Scranton	City	200	do	14		1		80	29	23	4	406	33		1	388	H. S. Spaulding
Do	Chicago & North Western Ry. Co.	151	do	14	[illegible]			95	33	11		438	25		4	403	Geo. M. Davidson
Boone County																	
Boone	City	3,010	Dresbach or underlying Cambrian sandstones.	10			4	152	64	310	22	300	871		128	1,711	W. S. Hendrixson
Do	do	50	Sand	27		1	1	101	34	12	3	450	1		4	409	Do.
Do	Chicago & North Western Ry. Co.	104	do	31				92	35	5		462			1	395	Geo. M. Davidson
Madrid	City	100	do	22		1	1	103	30	43		496	38		6	492	Geo. N. Prentiss
Do	J. Barclay	104	Drift	34		6	6	94	28	32		514	0		2	459	W. S. Hendrixson
Ogden	City	2,800	Below Saint Peter	10		7	4	139	[illegible]	231		[illegible]	736		59	1,381	Do.
Story County																	
Ames	City	97		28	[illegible]			78	32	10		392	16		3	366	Geo. M. Davidson
Do	Iowa State College	2,215	Jordan	3			4	35	15	391		204	516		204	1,270	J. B. Weems
Colo	Chicago & North Western Ry. Co.	374		11	1			83	33	91		400	188		9	616	Geo. M. Davidson
Maxwell	City	100		1.3	5			87	24	17		432	0			350	Geo. N. Prentiss
Nevada	do	980	Maquoketa	9		5	2.5	426	84	141	13	315	1,390		42	2,276	W. S. Hendrixson
Zearing	H. C. Wickham	300		27				90	31	18		496	13		.2	436	Do.

Analyses of water in the central district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Marshall County		Feet															
Marshalltown	Artificial Ice Co.	257		20			2	197	71	25	2	359	354	46	68	964	W. S. Hendrixson
Do.	City	30	Sand	11	6			65	20	13		268	46		5	307	Geo. M. Davidson
Rhodes	T. W. Dickey	174		12		5	1	118	48	93	8	368	381		3	851	Geo. N. Prentiss
State Center	City	161	Drift	22	14			363	136	341		1,062	1,254		7	2,668	Geo. M. Davidson
Do.	Farm well	170		22			7	136	42	118		548	286		9	887	Do.
Guthrie County																	
Bagley	Chicago, Milwaukee & St. Paul Ry. Co.	120	Cretaceous		2			91	33	11		422	29		2	379	Geo. N. Prentiss
Guthrie Center	City (7 wells)	42	Drift	21				66	18	15		214	49		14	290	W. S. Hendrixson
Herndon	H. Miller	110	Cretaceous					87	24	22		416	9		13	354	Geo. N. Prentiss
Do.		534						73	37	212		313	368		108	954	Do.
Stuart	City	90						90	27	32	2	408	18		2	390	W. S. Hendrixson
Dallas County																	
Perry	City (2 wells)	115	Sand		6			43	23	67		415			3	349	Geo. N. Prentiss
Do.	do	117	Do.		9			51	27	55		420			5	350	Do.
Polk County																	
Des Moines	City Library	375	Des Moines	14			3	237	53	559	7	312	1,569		107	2,706	W. S. Hendrixson
Do.	West Side School	286	do	7			.	21	9	509	5	582	530		85	1,459	
Do.	Courthouse	380	do	148			4	339	96	508		300	1,916		107	3,218	Floyd Davis
Do.	Greenwood Park	3,000	Dresbach or underlying Cambrian sandstones.	4.5		10	4	212	190	541	13	124	1,760		124	2,941	W. S. Hendrixson
Mitchellville	Industrial School	152	Mississippian	15		2	1	99	45	529	7	384	1,144		58	2,090	Do.
Do.	do	563	do	19		4	2	97	35	450		360	895		61	1,743	Do.

Runnells	Robert Blee	228	Des Moines	12	------	.5	1	108	39	715		414	1,520	---	43	2,645	Do.
Sheldahl	Chicago & North Western Ry. Co.	303	------------------------	7	6	----	-----	129	56	112		336	421	---	48	947	Geo. M. Davidson
Jasper County																	
Colfax	Sanitarium	371	Mississippian	10	-----	.2	1.5	211	99	420		260	1,505	---	29	2,406	H. S. Spaulding
Do	News Station	------	------ do	9	------	----	1	104	52	580		324	1,338	---	37	2,283	W. S. Hendrixson
Do	Mills Hotel	350	------ do	11	------	.7	1	285	97	463		260	1,495	---	27	2,460	H. S. Spaulding
Lynnville	City	255	------------------------	11	------	----	-----	83	30	32		274	161	---	6	460	Iowa Central Ry. Co.
Monroe	Chicago, Rock Island & Pacific Ry. Co.	287	------------------------	----	8	----	-----	124	45	83		426	301	---	5	779	F. O. Bunnell
Newton	City (drive)	50	River bottom	16	------	----	1.5	54	19	9		222	25	---	5	240	H. S. Spaulding
Prairie City	Chicago, Rock Island & Pacific Ry. Co.	360	Carboniferous	----	36	----	-----	331	126	41		662	1,110	---	5	1,980	F. O. Bunnell
Newton *b*	City	1,400	Maquoketa	37	16	----	-----	360	88	893		106	2,739	---	183	4,369	
Colfax	Grand Hotel	------	Mississippian	127	------	5	-----	706	77	405]	3	1,722	1,435	---	32	2,651	Louis G. Michael
Newton	Minneapolis & St. Louis Ry. Co.	450	------ do	9	------	----	-----	110	55	41		592	79	---	13	603	W. D. Wheeler

a Sum of the constituents minus one-half the bicarbonate radicle.
b Free CO_2=7,856 (?)

CHEMICAL COMPOSITION OF WATERS OF THE SOUTHEAST DISTRICT.

The rocks of the Mississippian and Pennsylvanian series, which lie nearest the surface in the southeast district, as a rule contain highly mineralized waters. The waters of the Saint Peter and the deeper aquifers are much better but are nevertheless more highly mineralized than the waters of the same aquifers farther to the north and east. In a number of deep wells the higher mineralization of the water may be ascribed to defective casing which allows the sulphated waters of the country rock to enter. When deep wells are being drilled the waters of each aquifer should be analyzed and all deleterious waters should be thoroughly cased out. Such precautions and the use of inner tubes leading directly to the lower aquifers will probably greatly lessen the danger of failure. The least promising part of the area is in Keokuk and Mahaska counties. In quantity, the artesian supply of the southeast district is unexcelled within the state.

Average mineral content of the waters of the southeast district of Iowa

[Parts per million.]

Source	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids *a*
16 deep wells	15	143	56	463	285	998	256	1,978
29 shallow wells	27	165	82	188	367	1,040	69	1,931

a Sum of the constituents minus one-half the bicarbonate radicle.

All deep wells of the southeast district yield hard, heavily mineralized waters. The best are the wells at Ottumwa and the very deep well in Crapo Park, Burlington. All other well waters at Burlington so far as analyzed are very hard. The great amount of solids of the wells reaching only into the Devonian may come largely from the Carboniferous, at any rate in the Clinton-Copeland Co.'s well, for that is cased only to a depth of 70 feet. It is evident that this water does not sensibly enter into the Crapo Park well, a fact which is difficult to understand, as the well is cased to 18 feet only. This water is very high in incrusting solids and also contains large amounts of sodium and potassium. Water of about the same amount of total solids but lower in calcium and magnesium and higher in alkalies and chlorides is found in the deep wells at Keokuk. This water as it occurs at either place can hardly be called suitable for any purposes save for extinguishing fires and sprinkling streets. The waters at Ottumwa, Washington, and even at Mount Pleasant, may be used if no better can be obtained and if a great deal of mineral matter is overlooked for the sake of probable organic purity.

The wells at Keokuk end in the Maquoketa, and those whose waters have been analyzed have about the same depths, 700 to 769 feet. The three deepest ones have about the same amounts of solids. The Young Men's Christian Association well is cased only to a depth of 56 feet, which is probably to rock, and hence this well, and probably the two deeper ones, receive water from all penetrated strata that are water-bearing, as the quality of their waters is the same. It seems probable also that at both Burlington and Keokuk no serious attempt was made to case out upper waters in the wells whose analyses are here given, though it ought to be easily practicable in wells of such depth.

Shallow wells from 100 to 300 feet deep seem to be rare in this section, for few could be found. Apparently, with the exceptions noted, the people are dependent on river water in the larger towns and on very shallow wells in the small towns and rural districts. The number of shallow wells investigated is too small to permit very definite generalizations to be made. With one or two exceptions all drift wells of the shallow sort supply soft water, while all wells which penetrate rock supply hard, usually very hard water.

Analyses of waters in the southeast district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Mahaska County		Feet															
New Sharon	Allen Bros.	227		14	----	3	3	124	71	409		522	1,026	----	58	1,969	E. B. Benger
Do.	City	155		17	----	----	1	83	24	15	1	396	2	----	5	346	W. S. Hendrixson
Stark	Chicago & North Western Ry.	40	Drift	14	----	----	2	374	139	75		416	1,262	----	6	2,277	Geo. M. Davidson
Do.	Farm well, 0.5 mile north of station	25		34	----	----	2	77	36	12		278	42	----	62	404	Do.
Southern Iowa Junction.	Farm well, 1¼ miles southwest.	185		20	----	----	1	93	27	17		428	18	----	5	393	Do.
Do.	Well near station	200		7	----	----	33	58	33	19		418	27	----	4	420	Do.
Do.	Farm well, 1.5 miles northeast	286		21	----	----	1	98	31	40		504	53	----	3	479	Do.
Keokuk County																	
Ollie	P. Hollingsworth	250		17	----	2	2.5	99	26	22		497	23	----	5	445	H. S. Spaulding
Richland	P. Vastine	75		20	----	1	1	82	24	21		407	8	----	7	367	E. B. Benger
Sigourney	City	24		----	----	----	3	40	10	53		268	19	----	8	267	Geo. N. Prentiss
What Cheer	Thompson & Walker.	90	Sandstone	24	11	----	----	269	102	138		474	841	----	85	1,707	Geo. M. Davidson
Keota	City	150		7	2	----	----	142	37	14		538	110	----	1	582	Roland Neal
Washington County																	
Washington	City	232		----	----	----	----	33	13	194		558	64	----	25	595	W. S. Hendrixson
Do.	City No. 1	1,617	Saint Lawrence	14	----	----	1	109	47	218	19	280	590	----	71	1,209	Do.
Do.	City No. 2	1,217	Saint Peter	10	----	----	3	113	45	367	19	288	810	----	123	1,634	Do.
Wellman	Chicago, Rock Island & Pacific Ry. Co.	129		----	4	----	----	97	41	37		214	196	----	81	563	F. O. Bunnell

Louisa County																	
Wapello	Chicago, Rock Island & Pacific Ry. Co.	60		----	14	----	----	62	10	22		200	51	----	18	277	F. O. Bunnell
Wapello County																	
Ottumwa	Young Men's Christian Association	------		13	------	----	1	96	31	368	20	298	[illegible]	----	141	1,5[illegible]	W. S. Hendrixson
Do.	John Morrell (2)	1,554	New Richmond	12	------	----	1	95	41	298	18	305	587	----	140	1,34[illegible]	Do.
Do.	J Morrell, No. 4	2,200	Oneota	11	------	----	1	96	35	247	16	308	500	----	119	1,17[illegible]	Do.
Do.	Artesian Well Co.	2,047	do	----	------	----	-----	90	37	265		356	474	----	119	1,165	L. W. Andrews
Do.	Mineral Springs Sanitarium Co.	314	Mississippian	125	------	24	-----	345	152	1,464		1,297	2,807	----	533	6,095	D. D. Carter
Do.	do	85		25	------	----	-----	54	26	167		472	152	----	28	688	W. S. Hendrixson
South Ottumwa	Typical drive	50		20	------	1	2	96	23	11		230	126	----	20	414	Do.
Farson	G. Thompson	100		----	------	----	9	97	32	43		544	11	----	7	471	Geo. N. Prentiss
Rutledge	Phillips Fuel Co.	42		----	------	----	-----	89	24	18		420	6	----	3	350	Do.
Eddyville	Spring	------		96	------	880	1,288	464	984	80		-----	15,112	(*b*)	8	18,912	T. E. Pope
Henry County																	
Mount Pleasant	Hospital for Insane	1,230	Saint Peter	14	------	3	1	102	37	326	12	262	669	----	151	1,440	W. S. Hendrixson
Do.	do	1,267	do	10	------	8	1	198	71	400	14	280	1,214	----	157	2,313	Do.
Winfield	Chicago, Burlington & Quincy R. R. Co.	70		----	------	----	-----	----	----	----	--	-----	------	----	----	370	M. H. Wickhorst
Des Moines County																	
Burlington	Murray Iron Works	1,000	Saint Peter	11	------	1	1	342	115	514	11	232	1,860	----	235	3,206	W. S. Hendrixson
Do.	Sanitary Milk Co.	484	Silurian	13	------	5	1	389	131	707	19	268	2,414	----	276	4,089	Do.
Do.	Crapo Park	2,430	Dresbach or underlying Cambrian sandstones.	13	------	----	1	79	25	253	11	274	386	----	161	1,066	Do.
Do.	Clinton - Copeland Co.	500	Silurian	13	------	----	2	398	140	783	21	260	2,338	----	276	4,101	Do.
Northfield		300		----	8	----	-----	93	33	2		398	28	----	9	372	F. O. Bunnell
Davis County																	
Bloomfield	City	1,817		74	5	----	-----	237	71	303		192	1.203	----	86	2,080	Dearborn Drug & Cnemical Works
Van Buren County																	
Cantril	Sam Teter	230		25	------	6	9	340	92	279		147	1,635	----	15	2,474	W. S. Hendrixson
Do.	O. J. Manning	300	Maquoketa	16	------	3	1	270	89	299		228	1,368	----	19	2,117	Do.
Farmington	City	300	Silurian (?)	13	------	----	2	340	112	442	15	248	1,658	----	230	2,936	Do.
Milton	Chicago, Burlington & Quincy R. R. Co.	135		----	------	----	-----	----	----	----	--	-----	------	----	----	725	M. H. Wickhorst

Analyses of waters in the southeast district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
		Feet															
Stockport	do	40														310	Do.
Lee County																	
Fort Madison	S. Atlee	110		12			1	90	37	428	15	272	505		48	1,652	W. S. Hendrixson
Do	Columbia Paper Co	689	Galena	7	14			150	22	501		514	587		429	1,967	Do.
Keokuk	Young Men's Christian Association	769	Silurian (?)	12			1	198	81	894	15	292	1,610		632	3,589	Do.
Do	Keokuk Pickle Co.	769	do	7			8	172	87	837		121	1,546		633	3,350	J. B. Weems
Do	Keokuk Poultry Co.	700	do	6			1	206	35	1,044		311	1,589		674	3,710	Do.

a Sum of the constituents minus one-half the bicarbonate radicle.
b Very strongly acid.

CHEMICAL COMPOSITION OF WATERS OF THE SOUTH-CENTRAL AND SOUTHWEST DISTRICTS.

There are few deep wells in the southwest and south-central districts, and the waters of these are without exception hard. Some of them are too heavily mineralized to be used for any purpose. Three wells in Marion county all contain more than 8,000 parts of solids. As shown by the well of Thomas Craig, near Knoxville, which is only 346 feet deep, the hard water probably comes from the upper rock strata, though it may come from the lower beds also. This conclusion is reached by comparing the water of this well with the waters from the deep wells at Pella and at Flagler. The similarity of the solids in quality and in quantity indicates that the waters have a common origin. The character of the water at Pella has been used, perhaps justly, to discourage deep drilling in that part of the state. It should be said however, that this water probably comes from strata lying very little, if any, deeper than those in the Craig well, and not from the Saint Peter, in which the well is supposed to have its footing. If this is true, it is not impossible that the hard water could be shut out and a reasonably good supply obtained by using deep casings, carefully put in, in borings of equal or greater depth in this vicinity. The Saint Peter alone did not seem to yield enough water in the Pella well, and the casing was raised so as to admit the harder water.

The best deep wells in the southwest and south-central districts are at Council Bluffs and at Dunlap, both near Missouri river. Though all are about equally high in mineral content, the wells at Council Bluffs have the advantage of containing only small amounts of calcium and magnesium, and on that account they may be rated as soft waters.

Two deep wells at Glenwood, about 2,000 feet deep, yield highly mineralized waters but have long been in use, one to supply the city and the other the institution for the feeble-minded. The latter well is supposed not to go below the Silurian and its water is better than that of the city well, which probably enters the Maquoketa, in containing less calcium and magnesium. This well has now been abandoned on account of contamination and insufficiency of water, and a new supply for the institution has been obtained from shallow wells in the alluvium near Missouri river. Water from one of the test wells contained 460 parts per million of solids.

The latest deep well to be drilled in this part of the state is at Bedford, in Taylor county, and reaches a depth of 2,000 feet. An analysis of water encountered at 1,300 feet showed 4,827 parts per million of solids, mostly salt, chlorine being 2,545 parts. Another vein of very different water was struck at about 2,000 feet. An analysis of water at this depth showed about half as much salt, though the total solids reached 5,373 parts per million. The lower water contains large amounts of calcium, magnesium, and sulphate radicle and the water last analyzed was a mixture in about equal volumes of the flows from the two sources.

From the data now at hand the outlook for good deep-well water in the southwest and south-central districts is not encouraging. The Bedford well reaches only into the Silurian at 2,000 feet, and its bottom is probably several hundred feet above the great sandstone formations, which are doubtfully productive of good water in quantity in that locality. Their depth is certainly at about the limit of practicable drilling, not to mention the great difficulties of putting down casings to sufficient depths to shut out the undesirable waters that have been encountered at every point where deep wells have been drilled.

Not only are the deep-well waters in this section highly mineralized, but the same is true of every water analyzed from a well which is known to enter rock. The Carboniferous and the Cretaceous cover the entire region and seemingly supply hard water. On the other hand, no other region of the state is so well supplied with small rivers having broad valleys that contain water-bearing sand layers. At least a dozen of these rivers or large branches of rivers flow through the south-central and southwest districts, generally in a southwesterly direction, and enter into the Missouri. Many towns get their water supplies from the sands in the flood plains or valleys of these rivers. Notable examples are Red Oak, Elliott, Griswold and Atlantic, on the Nishnabotna, and Clarinda, Villisca and Corning, on the Nodaway. Where water is thus obtainable driven or dug wells in river valleys in this part of the state are the best sources. Many districts away from rivers in Mahaska, Marion and Monroe counties find the water problem a serious one. In some localities gravel and sand layers in the drift supply abundant waters to driven or bored wells, and this is true over large portions of Mills, Page, Appanoose and probably Union counties. Union county seems to be particularly well supplied with water; at least four branches of Platte and Grand rivers flow across it, and C. A. White of Talmage writes that it contains very many unfailing springs, that there are large areas of sand and gravel which supply abundant water, and that there is probably not a farm in the county that can not easily have a constant supply of good water.

Average mineral content of waters in the south-central and southwest districts of Iowa.

[Parts per million.]

Source	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids *a*
13 deep wells	32	157	66	618	346	1,484	556	3,657
37 shallow wells	26	167	43	374	363	745	62	1,587

a Sum of the constituents minus one-half the bicarbonate radicle.

Analyses of water in the south-central district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids a	Name of Chemist
Adair County		Feet															
Fontanelle	J. H. Hubert	269	Cretaceous	20	----	3	1	231	69	412		264	1,322	----	84	2,274	W. S. Hendrixson
Orient	Chicago, Burlington & Quincy R. R. Co.	34	----	----	----	----	----	----	----	----		----	----	----	----	236	M. H. Wickhorst
Madison County																	
Winterset	Chicago, Rock Island & Pacific Ry. Co.	38x16	----	----	6	----	----	101	34	10		298	176	----	24	450	F. O. Bunnell
Warren County																	
Carlisle	P. Shoemaker	220	Des Moines	168	----	2	11	26	10	816		636	1,104	----	128	2,583	W. S. Hendrixson
Marion County																	
Columbia	F. Carruthers	150	Saint Louis	15	----	5	2	[illegible]	72	772		276	2,754	8	27	4,283	W. S. Hendrixson
Flagler	S. C. Johnson	752	Kinderhook	[illegible]	----	.4	3	486	167	2,236		306	4,839	----	925	8,831	Do.
Knoxville	Hospital for Inebriates.	326	Des Moines	[illegible]	----	4	3	303	52	436		262	1,600	----	18	2,553	Do.
Do	T. Craig	346	do	36	----	3	1	207	114	2,589		330	4,728	----	980	8,823	Do.
Do	P. M. Stentz	142	Sandstone	28	----	----	5	80	19	14		256	38	----	10	323	Do.
Pella	City	1,803	Saint Peter	10	----	4	3	488	148	2,107		280	4,678	----	775	8,353	Do.
Pleasantville	J. Worthington	180	Des Moines (?)	10	----	1	1	321	95	886		330	2,515	----	128	4,122	Do.

Union County																	
Talmage	Mormon Spring	------	----	31	----	1	1	142	21	17		374	47	----	6	453	W. S. Hendrixson
Lorimer	Private well	450	----	----	----	----	----	369	154	(*b*)		304	1,243	----	(*b*)	3,360	W. H. Chadbourn
Shannon	Chicago Great Western Ry. Co.	38	----	----	----	----	----	18	15	161		388	154	----	9	551	Do.
Kent	Chicago, Burlington & Quincy R. R. Co.	161	----	----	----	----	----	----	----	----		----	----	----	----	951	M. H. Wickhorst
Lucas County																	
Woodburn	Mrs. J. R. Rhodes	270	Drift	13	----	3	2	157	46	577		261	1,405	----	17	2,350	H. S. Spaulding
Monroe County																	
No. 10 Junction	Chicago & North Western Ry. Co.	1,345	Silurian	12	----	----	----	278	59	602		580	1,496	----	142	2,879	Geo. M. Davidson
Ringgold County																	
Diagonal	Chicago Great Western Ry. Co.	36	----	----	----	----	----	65	20	(*c*)		284	10	----	(*c*)	335	W. H. Chadbourn
Kellerton	Robt. Hall	375	Des Moines	55	----	5	9	249	87	521		439	1,477	----	46	2,673	H. S. Spaulding
Do.	L. Myers	400	----	11	----	2	4	85	53	793		397	1,417	----	244	2,830	Do.
Decatur County																	
Leon	Wm. Haslitt	803	Des Moines	*d* 53	----	8	2	95	36	735		376	1,489	----	90	2,696	W. S. Hendrixson
Wayne County																	
Sewal	Chicago, Milwaukee & St. Paul Ry. Co.	80	----	----	3	----	----	151	51	41		526	206	----	15	735	Geo. N. Prentiss
Cambria	Chicago, Burlington & Quincy R. R. Co.	16	----	----	----	----	----	----	----	----		----	----	----	----	400	M. H. Wickhorst
Appanoose County																	
Centerville	City (No. 1)	1,540	Silurian	10	2	----	----	263	90	755		90	1,961	----	339	3,465	J. E. Siebel
Do.	City (No. 2)	2,054	New Richmond	35	----	3	1	191	66	555		274	1,229	----	328	2,545	W. S. Hendrixson
Moulton	Electric Light Co.	400	Des Moines	7	----	2	1	355	77	373	8	170	1,764	----	20	2,687	Do.

a Sum of constituents minus one-half the bicarbonate radicle.
b "Other alkalies," 1,442 parts.
c "Other alkalies," 98 parts.
d Including clay.

Analyses of waters in the southwest district of Iowa.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica [SiO_2]	Oxides of iron and aluminum [$Fe_2O_3+Al_2O_3$] a	Iron [Fe]	Aluminum [Al]	Calcium [Ca]	Magnesium [Mg]	Sodium [Na]	Potassium [K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Nitrate radicle [NO_3]	Chlorine [Cl]	Total solids a	Name of Chemist
Harrison County		Feet															
Dunlap	City	1,535	Saint Peter	8	----	0	3	176	72	146	27	272	773	----	33	1,374	W. S. Hendrixson
Do.	Chicago & North Western Ry. Co.	60		25	3	----	----	138	45	[illegible]		384	234	----	21	688	Geo. M. Davidson
Logan	City	821		10	----	.3	2	85	15	461		411	728	----	121	1,578	E. B. Benger
Missouri Valley	Chicago & North Western Ry. Co. (shops).	90		[illegible]	3	----	----	112	41	14		482	62	----	14	509	Geo. M. Davidson
Do.	Farm well	328		24	12	----	----	90	52	45		524	68	----	21	584	Do.
Mondamin	Chicago & North Western Ry. Co.	90		26	8	----	----	160	55	35		724	[illegible]	----	4	735	Do.
Shelby County																	
Harlan	City	30-40		18	2	----	----	80	31	12		341	37	----	18	370	Geo. M. Davidson
Audubon County																	
Audubon	City	85		27	----	1	3	205	43	36		250	[illegible]	25	82	916	W. S. Hendrixson
Pottawattamie County																	
Council Bluffs	Woodward Candy Co.	830	Basal Mississippian (?)	----	----	----	----	28	22	414		288	666	----	80	1,363	W. H. Chadbourn
Do.	School for Deaf	1,091	Silurian (?)	9	----	----	2	40	9	416	4	312	649	----	78	1,363	Floyd Davis
Do.	C. Hafer	138		31	----	.6	2.4	104	23	24		442	29	----	6	441	H. S. Spaulding
Do.	do	100		26	----	----	2	109	25	20		430	34	----	5	436	Do.

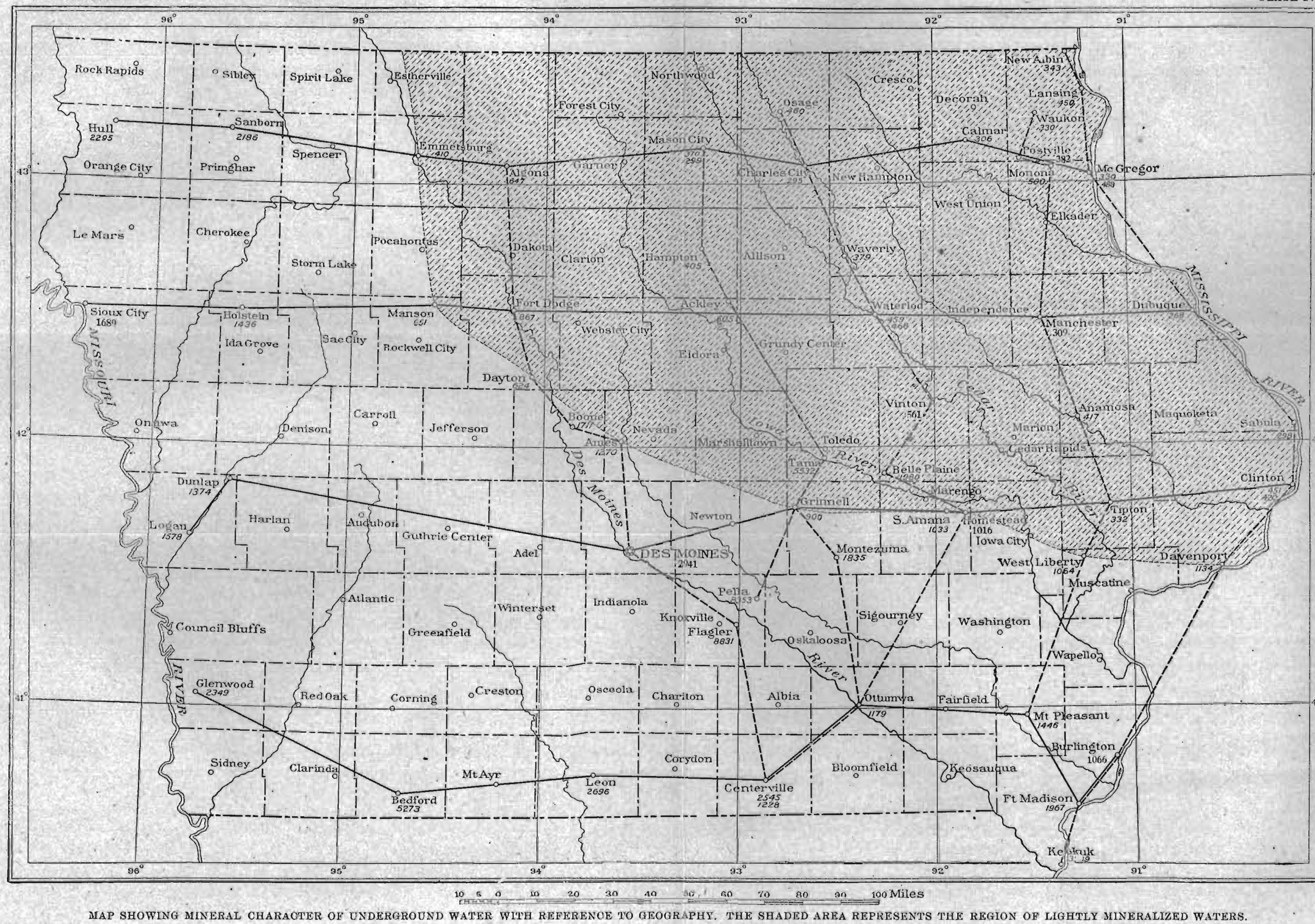
Honey Creek	Chicago & North Western Ry. Co.	118		22			1	126	41	162		348	403		87	1,016	Geo. M. Davidson
McClelland	Chicago Great Western Ry. Co.	225						87	39	28		438	30			393	Do.
Minden	City	50						105	34	31		410	60		47	482	W. H. Chadbourn
Neola	Chicago, Milwaukee & St. Paul Ry. Co.	100						70	23	14		354	2			286	Geo. N. Prentiss
Cass County																	
Anita	City	207	Sandstone	28		.1	2	304	84	125		802	970		12	1,721	W. S. Hendrixson
Atlantic	do *b*	40-60	Alluvium, river bottom.		5			75	20	7		274	40		10	294	F. O. Bunnell
Griswold	W. H. Spencer	100	Drift	20		3	.5	48	13	8	2	230	6		1.1	217	H. S. Spaulding
Mills County																	
Glenwood	Institute for Feeble-minded.	1,910	Silurian	131	16			37	11	647		486	754		185	2,027	W. S. Hendrixson
Do.	Institute for Feeble Minded (test well).		Missouri bottom	12			2	97	41	27		504	25		4	460	Do.
Do.	City	2,000	Maquoketa	22	9			75	26	790		518	886		282	2,349	Do.
Hastings	Chicago, Burlington & Quincy R. R. Co.	41														416	M. H. Wickhorst
Montgomery County																	
Red Oak	City	38	River bed	10			3	43	9	14		226	37		5	234	W. S. Hendrixson
Villisca	City (No. 1)		Alluvium, river bottom.	*c* 404				36	13	5		150	18		4	557	Do.
Do.	City (No. 2)		do	28		2	2	50	15	20		152	31		43	270	Do.
Adams County																	
Corning	City		do	18		7	5	92	21	[illegible]		262	100		31	432	W. S. Hendrixson
Fremont County																	
Hamburg	Chicago, Burlington & Quincy R. R. Co.	75														530	M. H. Wickhorst
McPaul	do	40														500	Do.

Analyses of waters in the southwest district of Iowa—Continued.

[Parts per million.]

Locality	Owner	Depth of well	Name of Lowest Stratum	Silica (SiO_2)	Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Nitrate radicle (NO_3)	Chlorine (Cl)	Total solids *a*	Name of Chemist
Page County		Feet															
Clarinda	Chicago, Burlington & Quincy R. R. Co.	56														909	M. H. Wickhorst
Do	do	60														270	Do.
Shenandoah	do	62														718	Do.
Taylor County																	
Bedford	Water Co. (1)	1,300		10			2	77	34	1,768		312	235		2,545	4,827	W. S. Hendrixson
Do	Water Co. (2)	2,002	Silurian	18		1	1	486	116	1,161		300	1,920		1,420	5,273	Do.

a Sum of constituents minus one-half the bicarbonate radicle.
b City water from many drive wells.
c Including clay; excluded from averages.



MAP SHOWING MINERAL CHARACTER OF UNDERGROUND WATER WITH REFERENCE TO GEOGRAPHY. THE SHADED AREA REPRESENTS THE REGION OF LIGHTLY MINERALIZED WATERS.

SUMMARY OF QUALITY OF IOWA WATERS, BY DISTRICTS.

WATERS OF THE DEEP WELLS.

QUALITY.

In this paper all wells that penetrate at least the Saint Peter sandstone, and all other wells more than 700 feet deep are considered to be deep wells.

The average mineral content of the deep wells in the various districts is summarized in the following table:

Average mineral content of waters from deep wells in Iowa.

[Parts per million.]

District	Number of analyses averaged	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids [a]
Northeast	30	10	63	31	28	321	38	24	851
North-central	7	11	87	33	20	328	92	14	439
Northwest	9	16	210	67	181	373	719	10	1,425
East-Central	35	10	103	47	182	326	425	83	978
Central	10	14	174	62	286	262	947	19	1,759
Southeast	16	15	143	56	463	285	998	256	1,978
South-central and southwest	13	32	157	66	618	346	1,484	556	3,657

[a] Sum of the constituents minus one-half the bicarbonate radicle.

The deep-well waters of the northeast, north-central, and east-central districts are decidedly lower in the amount of mineral matter they contain than the waters of the other districts, and it may be inferred that increase of mineral content progresses from the northeast to the southwest corner of the state.

The change in the mineral content is, however, abrupt, and not progressive. (See Pl. IV.) This can be strikingly illustrated by tabulating the total solids of the deep waters along north-south and east-west lines across the state. In the first tabulation figures for waters along east-west lines are given with the locations and depths of the wells, the sharp transition in amount of dissolved mineral matter on each line being indicated by heavy rules. Column A represents the waters of wells beginning at McGregor, Clayton county, and going west to Big Sioux river along a line passing through the second tier of counties from the north. Column B contains wells for the most part in the fourth tier of counties from the north, along a line beginning at Dubuque and ending at Sioux City. Column C includes wells mostly in the sixth tier of counties beginning at Clinton and ending at Logan in Harrison county. The figure for Grinnell represents the best deep water found there, that of city well No. 4; the water from most of the Grinnell wells contains about 1,200 parts of solids per million, a great change having taken place since the first well was put down in 1894, doubtless owing to the imperfect casing of Carboniferous and Silurian waters. Column D represents wells in the eighth and ninth (the two southernmost) tiers of counties. Fewer wells have been drilled in this part of the state than elsewhere, but these are sufficient to show that all the present wells along the southern line yield waters of high mineral content.

Change in total solids in well waters along east-west lines.

A.			B.		
Location of well	Depth	Total Solids	Location of well	Depth	Total Solids
	Feet	Parts per million		Feet	Parts per million
McGregor, City No. 1	520	488	Dubuque[b]	1,200	268
Calmar	1,228	306	Manchester	1,870	309
Charles City	1,688	295	Waterloo	1,373	468
Mason City[a]	651	370	Fort Dodge	1,827	867
Algona	1,050	647	Manson	1,954	651
Emmetsburg	874	410	Holstein	2,004	1,436
Sanborn	1,250	2,186	Sioux City	2,011	1,689
Hull	1,256	2,295			

C.			D.		
Location of well	Depth	Total Solids	Location of well	Depth	Total Solids
	Feet	Parts per million		Feet	Parts per million
Clinton	1,065	451	Burlington[d]	2,430	1,066
Tipton	2,696	332	Mount Pleasant[e]	1,230	1,446
Homestead	2,224	1,016	Fort Madison	689	1,967
Amana	1,640	1,033	Ottumwa[f]	2,200	1,179
Grinnell, City No. 2	2,002	881	Centerville	2,054	2,545
Des Moines[c]	3,000	2,941	Leon	803	2,696
Dunlap	1,535	1,374	Bedford	2,002	5,273
Logan	821	1,578	Glenwood[g]	2,000	2,349

[a] City well No. 2.
[b] City 8-inch well.
[c] Greenwood Park well.
[d] Crapo Park well.
[e] Well at State Hospital.
[f] Well of J. Morrell Co.
[g] City well.

The same sharp change in the mineral content of the deep waters may be observed along north-south lines. Wells yielding soft water occur farther south the nearer they are to Mississippi river—that is, such wells occur near the river as far south as the parallel of Des Moines—but on the meridian of Des Moines only wells near the northern border of Iowa supply soft water. West of this meridian only two or three deep wells have slightly mineralized water. The relations of the north and south lines are shown in Plate IV. Column A in the next table contains the total solids and depths of deep wells on or near Mississippi river, beginning at New Albin and ending at Keokuk. Column B shows the mineral content of wells near, but not on, Mississippi river, beginning at Waukon in Allamakee county and ending at Mount Pleasant in Henry county. Column C gives the amount of mineral matter in wells beginning at Osage on the north and extending south in a line approximately parallel to the eastern border of the state and ending at Centerville. Column D leaves much to be desired. The well at Tama is only 861 feet deep and probably foots in the Silurian, for its mineral content is higher than would be expected in the lower sandstones. The region along Iowa river in Tama, Benton and Iowa counties is one having waters high in mineral content in the drift and probably for some distance in the strata underlying the drift, as the shallow wells penetrating these strata show. It may be that the wells of this region are contaminated by the heavily mineralized waters from beds far above the strata in which the wells foot. The well at Montezuma, depth reported 2,800 feet, had long been unused at the time the sample was taken, but the sample was taken only after the well had been pumped an hour or more. The lowest geologic formation this well penetrates is unknown. Owing to uncertainties regarding the Montezuma well the one at Pella was also included in the series. Column E begins with the well at Emmetsburg and ends with that at Centerville. In general the wells are near Des Moines river. High mineral content is found a little farther north on this line than on the next preceding line to the east. The line connecting the wells north of Boone marks about the western limit of lightly mineralized waters in deep wells, and with the exception of the well at Emmetsburg these wells contain considerably more mineral matter than the wells in the same latitude in the next line east beginning at Osage.

Change in total solids in well waters along north-south lines.

A.

Location	Depth	Total solids
	Feet	Parts per mil.
New Albin	500	343
Lansing	668	450
Village Creek	750	372
McGregor	520	488
Dubuque *a*	1,200	268
Sabula	973	298
Clinton *b*	1,226	420
Davenport *c*	1,067	1,134
Burlington *d*	2,430	1,066
Fort Madison	689	1,967
Keokuk *e*	769	3,589.

B.

Location	Depth	Total solids
	Feet	Parts per mil.
Waukon	600	330
Postville, city	515	382
Monona	420	500
Manchester	1,870	309
Anamosa	2,200	417
Tipton	2,696	332
West Liberty	1,768	1,064
Mt. Pleasant	1,239	1,446

C.

Location	Depth	Total solids
	Feet	Parts per mil.
Osage	780	460
Charles City	1,588	295
Waverly	1,740	379
Waterloo	1,373	428
Vinton	1,402	561
Belle Plaine	1,520	1,980
Homestead	2,224	1,016
Ottumwa	2,200	1,179
Centerville	2,054	1,228

D.

Location	Depth	Total Solids
	Feet	Parts per million
Mason City	862	299
Hampton	1,708	405
Ackley	2,032	605
Tama	861	5,532
Grinnell	2,020	900
Montezuma	(?)2,800	1,835
Pella	1,803	8,353
Ottumwa	2,200	1,179

E.

Location	Depth	Total Solids
	Feet	Parts per million
Emmetsburg	874	410
Algona	1,050	647
Fort Dodge	1,827	867
Dayton	688	924
Boone	3,010	1,711
Ames	2,215	1,270
Des Moines	3,000	2,941
Flagler	752	8,831
Centerville	2,054	*f* 1,228

a City 8-inch well.
b Sugar Refining Co.
c Davenport Ice Co.
d Crapo Park.
e Young Men's Christian Association.
f The water of this well was analyzed five times at intervals of about a year. The total solids were 1,228 in the first analysis and 2,545 in the fourth.

DISTRIBUTION OF HARD AND SOFT WATERS.

The preceding tables show that the change from lightly mineralized to very hard waters from north to south and from east to west is not gradual, as might be expected, but is sudden, waters containing almost as small amounts of mineral matter as any in the state giving place to waters containing two or three times as much. The dividing line between these two regions of high and low mineralized waters is approximately shown on Plate IV. It starts at Davenport, on Mississippi river, and runs west to Grinnell, then swings in a wide arc northward through Ames, Manson and Emmetsburg. This location, however, should not be too strictly interpreted. Some wells supplying hard water are north of this line, particularly at Tama and at Belle Plaine. Good waters are usually found northeast of the line if the wells have been properly cased and are kept in good condition. Reference to the geologic map of Iowa (Pl. I, pocket) and to the account of geologic formations (pp. 105-137) brings out the relations between the quality of the deep waters and the character of the rocks from which they come and makes it clear why the difference in mineral content occurs. The part of the state northeast of the dividing line (Pl. IV) includes the region where the older sandstones and limestones lie immediately under the surface covering of drift. It also includes considerable areas of the Carboniferous, whose formations yield hard waters in many places. The formations of this system northeast of the line are, however, the older ones whose waters are less objectionable than those of the later deposits, and they lie so near the surface that their waters can be cased out, thus permitting the entrance of only the good waters from the older rocks underneath. If the area were restricted so as to exclude the Carboniferous entirely—that is, if the line between the Devonian and the Carboniferous were taken as the southwestern boundary—then practically no deep wells yielding hard waters would be included. With few exceptions the total solids in wells northeast of such line are less than 500 parts per million, and in most of these are less than 400 parts. A few notable exceptions occur, as at Davenport and Amana and at McGregor, where the 1,000-foot well going into the basal sandstone yields water containing considerable salt, whereas wells about 500 feet deep at the same place yield excellent water. The chief difficulty with the Davenport water is salt, but the amount is small. Both Davenport and Amana are apparently on the border of the Devonian and very near the Carboniferous.

With the present material used in casings and the methods employed in finishing wells, experience shows that outside of the northeastern area mentioned above it is very difficult, perhaps wholly impracticable, to procure from the deep-lying sandstones or any other deep-lying stratum water comparable in quality with that yielded by most of the deep wells in the northeastern part of the state. The strata bearing the very hard waters lie too deep to permit the successful and permanent casing out of these waters, and in the southwestern part of the state the lower sandstones seem to lie too deep to make it practicable to reach them with the drill. This practical difficulty of casing out the upper bad waters apparently explains why some wells within the Carboniferous area yield good water while others yield bad water. Future improvements in methods of protecting deep wells against the influx of undesirable waters from strata that may be penetrated may result in extension of the area of wells yielding water of low mineral content.

The waters of deep wells outside the district of good waters are not necessarily so highly mineralized as to be unfit for use, though several of them belong to this class. The majority belong to that class of waters which may be used for municipal supplies if none more satisfactory is available. Only about twenty-eight cities and towns have wells more than 750 feet deep. Some places have two or more wells, making the total number of deep wells in the district of poor water about forty. For the most part they are located in the southeast and northwest districts of the state. The south-central portion of the state has very few deep wells. In the three southern tiers of counties west of Ottumwa and extending to the counties bordering on Missouri river seventeen counties contain only three deep wells—those at Knoxville, Centerville and Bedford. A study of the records of the forty wells shows that only two, at Rockwell City and Manson, both just outside of the area of good well water already defined, contain less than 1,000 parts of solids per million. The average of the total solids for the wells in the twenty-eight towns, taking only one typical well in places where there are two or more, is 2,434 parts per million. From all the facts it seems probable that the southwestern part of the state will have to depend mainly on water supplies from shallow wells in drift and in river alluvium or on treated water from the rivers themselves.

WATERS OF THE SHALLOW WELLS.

The term "shallow wells" is used in this paper to describe wells penetrating only the drift and others that do not penetrate any of the great water-bearing sandstones. Definite statements like those used for deep wells can not be made regarding the relations between the geographic location and the mineral content of shallow wells. The averages by districts of the analyses of water from shallow wells in Iowa are repeated here for comparison. (See fig. 2.)

Average mineral content of the waters from shallow wells in Iowa.

(Parts per million).

District	Number of analyses averaged	Silica [SiO_2]	Calcium [Ca]	Magnesium [Mg]	Sodium and potassium [Na+K]	Bicarbonate radicle [HCO_3]	Sulphate radicle [SO_4]	Chlorine [Cl]	Total solids
Northeast				32	16	347	83	12	388
North-central	37	18	99	32	253	418	68	8.8	454
Northwest	60	24	160	48	60	420	321	62	857
East-central	45	14	177	58	90	360	495	25	1,031
Central	69	23	124	44	125	446	344	88	873
Southeast	29	27	165	82	188	367	1,040	69	1,931
South-central & southwest	37	26	167	43	374	363	745	62	1,587

The amounts of mineral matter in the waters of the shallow wells in general parallel those of the waters of the deep wells in the same localities, but the relation is only general and marked exceptions are frequent. Shallow wells derive their waters more from the country immediately surrounding them, and the character of their waters, therefore, depends more largely on local conditions. Some drift wells only a few miles apart show very different amounts of mineral matter. In certain areas the drift waters are notably hard; in others they are soft. Many wells, especially in the southern part of the state, derive their waters from the sands of river flood plains. Their waters are usually soft, as a rule containing very little more mineral matter than the waters of the rivers themselves.

CHAPTER VI.

MUNICIPAL, DOMESTIC AND INDUSTRIAL WATER SUPPLIES.

BY W. S. HENDRIXSON.

SOURCES OF SUPPLY

Iowa has few rivers capable of supplying sufficient water throughout the year to cities of considerable size. According to the best opinion of the present time there are few rivers and lakes in any part of the country that are capable of supplying water suitable for drinking without filtration. The time has probably passed when the water from any river within the state or from any bordering river may be used with safety without treatment.

The Iowa lakes are few, small, and shallow, and consist chiefly of one group near the northern border of the state well to the west, in Dickinson, Emmet, Clay and Palo Alto counties. No large towns are near them, and with one or two exceptions the smaller towns of that vicinity draw their water from other sources.

But although Iowa has few rivers or lakes affording potable water through a considerable portion of the year, the conditions are unusually favorable for the storage of ground water and its easy utilization. Most of the features that tend to decrease the amount of surface water are features that tend to produce a large supply of ground water; the level surface that gives the rivers slow currents and wide bottoms and flood plains and the deep drift that affords storage combine to make the run-off small and the absorption of water by the soil large.

If the shallow wells only a few feet deep, which foot below the water line during most of the year and derive their water from seepage, are left out of account, there are three main sources of ground water in Iowa—the drift, the alluvial sands and gravels in the river valleys, and the sandstone and limestone formations.

Nearly the whole state is covered by deep drift, containing extensive sand and gravel beds, usually near or just above the stratified rock. The beds afford storage for large quantities of water, which in most localities is easily reached by the bored well or drive point. In many regions these layers seem to be in the form of basins or troughs and in such localities many wells flow.

As a rule the small rivers of Iowa meander with low velocity through wide valleys instead of cutting the deep channels common in more rugged country. In such valleys shallow, bored, or driven wells obtain water from the drift layers of sand which may dip toward the river or from the so-called underflow of the river alluvium. Commonly the waters of wells in the river alluvium are softer than drift water, the mineral content in some wells being nearly as low as in the water from the rivers on whose banks the wells are located. Water supplies from this source are numerous, especially in the southwestern part of the state, where there are many such small rivers and streams and where water from other sources is not so abundant or easily reached. Good wells supplying water from this source have been driven or dug to depths of thirty to sixty feet at Red Oak, Griswold, Elliott and Atlantic, all on Nishnabotna river. The average mineral content of their water is usually less than that of the drift wells and does not greatly exceed that of the average river water in that section of the state.

The lower sandstones furnish an abundant supply of fair to good water to most of the deep wells of Iowa. A few deep wells in the southern and southwestern parts of the state do not reach these sandstones, which in the regions named lie at depths so great that it is hardly practicable to reach them with the drill or to case out the hard waters of the strata above them.

Leaving out of account water supplies for fire protection only, 324 towns[1] have waterworks of the more highly developed sort with standpipes, reservoirs, street mains and fire taps. (See Pl. I, in pocket.) Many towns of fewer than 200 inhabitants are thus supplied with waterworks, and the fact indicates much for the prosperity and progressiveness of the people. Of the 324 towns, only six draw their water supplies from lakes or artificial ponds, chiefly the latter. Twenty-four towns get their water from rivers and 294 from wells. The urban population supplied from lakes and ponds was 21,000; from rivers, 341,700; and from wells, 534,500.

From these figures it appears that about 60 per cent of the population of towns having water suplies use well water. It should be remembered, moreover, that the people of the towns without public water suplies and nearly the whole of the rural population use well water. The total population in 1900 was 2,231,853, of which about 84 per cent used well water and about 16 per cent water from other sources. The population is 1910 was 2,224,721, but it is not probable that the percentage using well water has markedly changed.

The requirements for ground water are likely to increase more rapidly than the population. Many of the 324 towns in Iowa having water systems of some sort are villages of 150 to 300 inhabitants, and many towns of 500 to 2,000 inhabitants now without waterworks will be obliged to provide them in the near future. It is certain that many towns will outgrow their water systems and must find means of enlargement. In fact, many municipalities have been obliged to put down more wells, and more often to change from shallow wells having a local supply of water from the drift to deep wells having their source of supply in the deep-lying sandstone strata.

Artesian wells in Iowa, excluding flowing wells in drift and country rock, now exceed 250, and the amount of capital invested in them probably reaches well up to $750,000. Artesian wells in Iowa are used for municipal supply, for state institutions, for hotels, hospitals and office buildings, for baths and swimming

[1]Based on figures of the Underwriters' handbook of Iowa, in which are given all towns, with their population and brief description of their means of fire protection.

pools, for railway locomotive and shop supply, for stock farms, and for a wide variety of industries, such as packing houses, gas plants, glucose factories, breweries and bottling works, lumber, woolen, paper and powder mills, soap factories, condensed milk factories, creameries and dairies, ice plants and iron works. In one place they have furnished power for a city electric plant.

It is interesting to note the development in stock wells on Iowa farms. The primitive stock well, dug only a few feet deep in a swale and fitted with a hand pump, has always been inadequate and has failed utterly in times of drought. The live stock interests have developed so rapidly that the need of perennial supplies of plenty of good water has been keenly felt, and as a result many farms have been provided with wells 100 to 500 feet deep, and some with wells 1,000 feet deep or more. In such wells pumps operated by windmills or gasoline engines are used instead of hand pumps. In the last few years the farming population has greatly increased in wealth, the values of farm lands have doubled and even trebled, and the advantages of a never failing supply of good water for stock and for domestic use are being more and more appreciated. These facts make it probable that the deep farm well will soon become the general source of water supply of the rural population in those parts of the state where satisfactory deep water-bearing formations exist.

Underground water is thus the chief source of water supply in Iowa for all purposes; and it does not seem probable that it will ever assume less importance relatively than it now holds. On the contrary, there are reasons why its importance should increase. With the growth of the population it seems likely that river water will become even more unsatisfactory in quality for municipal supplies, though it is possible that improved methods of filtration for smaller cities and towns may to some extent remove the difficulty due to pollution.

ADEQUACY OF WATER SUPPLY

The storage capacity of the aquifers which supply the Iowa deep wells is conditioned by their thickness, extent and porosity. Their supply of water depends on the area of their outcrop—

the area from which their waters are gathered—and on the rainfall in this area. Without going into any elaborate calculations it may be said that all conditions necessary for an abundant and continual yield are so fully met that the storage capacity of the Iowa water beds over any large area is far in excess of any possible draft upon them. Locally they may be overdrawn, but for the artesian field of Iowa as a whole there need not be the slightest apprehension of any diminution of supply. The maximum yield of wells is not limited by the present rainfall on the collecting area, by the absorption over the area, nor by the storage capacity of the basin, but by the conductivity of the rocks.

The yield of the Iowa deep wells is comparable with that of the deep wells of Minnesota, Wisconsin and Illinois, which draw water from the same formations. It seems at least equal to the yield of the wells of the artesian basin of New Jersey, where as light or lighter pressures prevail. It is considerably less than the yield of wells in the artesian basin of the Dakotas, chiefly because of the lower pressure in the Iowa field, which in turn is due to the more gentle dip of the Iowa aquifers —to the lower relative height of the area of supply.

SELECTION OF SOURCE OF SUPPLY

Emphasis must be laid on the fact that the writers of this report offer no specific advice as to municipal or other water supplies. They hold no brief for artesian wells in preference to other sources of supply, such as shallow wells or river waters filtered by any effective method. No city supply should be chosen until all possible supplies have been carefully investigated. Some towns of the state have rested content with a scanty supply of impure water, where pure artesian water could be cheaply obtained in large quantities; others have sunk expensive artesian wells where a far larger and more permanent supply of good water could have been more cheaply obtained and maintained from shallow wells, for example, in drift gravels of adjacent river valleys. But in the selection of a supply the sinking of a deep well will usually be considered, and any information as to the probable depth, quality and quantity of artesian waters will be of value whatever source of supply is chosen.

WELL DRILLING

DEEP WELLS.

No new methods in drilling deep wells in Iowa have been introduced since the publication of W. H. Norton's report on the artesian wells of the state in 1897.[1] The following description, summarized from that report, is therefore equally applicable at the present time:

To drill an even and straight tube a quarter or a half mile in depth requires experience and a high degree of mechanical skill. Deep-well drilling has become a special trade. Only one deep well in the state has been put down by amateur labor, and this proved a costly experiment whose repetition is not recommended. Most of the wells in Iowa have been drilled by firms whose territory is much wider than the limits of the state, and the methods and the machinery which they use in Iowa present nothing novel. In all drilling so far the drill has been the ordinary plunge or churn drill, essentially the same in action as that employed in sinking common drilled wells. The diamond drill has been used only in search for coal and building stone.

The rig differs slightly from that used in the oil fields of Pennsylvania and Ohio, and so fully described by Carll[2] and by Newell.[3]

The derrick tower is commonly about 18 feet square at the base and 60 feet high. An adjoining shed contains the forge at which the tools are dressed and an engine of 15 or 20 horsepower by which the drill is operated and the tools raised and lowered in the well. The drill consists of a steel chisel-shaped bit, screwed to an iron auger stem, to the upper end of which is fastened the "slips" or "jars." These consist of two slotted iron links joined together by a crosshead and crotch slot permitting a vertical play or slip, one upon the other, of about 13 inches, in about the same manner as the play of two links of a chain. The bit, the auger stem, and the lower member of the jars, thus fastened together, fall with each downward stroke about 20 inches and deliver a cutting and crushing blow of about 3,500 foot-pounds upon the rock. On the upward stroke the weight of the rig above the union of the two members of the jars delivers an upward blow whose purpose is to jar loose the drill beneath. No sinker bar is used above the jars. In some Iowa wells the string of drilling tools just mentioned has been swung from a rope, but in most wells rods of wood have been used, each about 33 feet long, with iron couplings. The string of rods and drill is attached by a swivel and heavy iron chain to the end of the walking beam, which plays up and down above the mouth of the tube. This chain is wrapped several times about the end of the beam and is let out little by little as the drill cuts deeper and deeper into the rock. The temper screw used for this purpose in the oil regions is not generally employed.

[1]Norton, W. H., Artesian wells of Iowa: Iowa Geol. Survey, vol. 6, 1897, pp. 115-428. See also Bowman, Isaiah, Well-drilling methods: Water-Supply Paper, U. S. Geol. Survey No. 257, 1911.

[2]Carll, J. F., Geology of the oil regions: Second Geol. Survey Pennsylvania. Rept. III, 1880, pp. 284-330.

[3]Newell, F. H., Drilling and care of oil wells: Ohio Geol. Survey, vol. 6, 1889, pp. 476-497.

Month after month the same tedious routine continues. Night and day a driller sits at the bench over the boring. As the rods rise and fall with the monotonous motion of the walking beam, he slowly twists them round and round so that the drill may strike every portion of the bottom in its rotation and drill the hole round and true. So simple is this, apparently, that a boy could do it. But the experienced driller feels every stroke of the drill and the movement of the jars, and interprets each vibration passing upward from a thousand feet below. A tyro in his place would churn the water without striking bottom and never know it. When no accidents delay, the drill cuts its way downward with surprising rapidity, making sometimes 60 or 70 feet a day. Every few feet the bore becomes clogged with the chips from the drill. The whole string is then hoisted and the hole cleaned out with the sand pump—a bucket with a suction valve at the bottom—and the drill is again lowered. This interruption takes less time than one would suppose. In hoisting the string the foreman sits with his left hand on the hoist lever and his right on the brake. The scaffold man stands on a platform in the tower about the length of a rod above the bench. The third man of the shift stands at the bench, catch wrench in hand. The string is rapidly hoisted by the engine; as soon as the upper end of the second rod from the top appears above the bench the brake is applied to the hoist, the string stops, the second rod is grasped by the wrench under the collar of the upper end. With the weight of the string thus resting on the wrench and the bench, the scaffold man and the man at the bench together uncouple the upper rod from its connections above and below and set it at one side. The swivel whirls down and is coupled to the second rod, the hoist lever is pulled, the string rises, the third rod is caught fast, the second uncoupled, and so the work goes on. To hoist 1,600 feet of rods and tools needs only 20 minutes, and less time is taken in lowering them again.

Scarcely a well is drilled without more or less time being lost by accidents. Fragments of rocks become detached from the side of the shaft, fall, and wedge in with the string, preventing the slips from doing their work in jarring loose the drill. As soon as the drill stops, the sediment, with which the water is thick, settles about it, fastening it so securely that it can not be dislodged without special instruments. Fishing for drills and other lost tools may be the longest and most costly part of drilling a deep well.

Occosionally the drill strikes a slanting crevice and slips to one side. If this difficulty is not met at once the boring is deflected from vertical and the drill soon becomes fast. Some crevices can be filled, but most of them must be passed by a special tool or by casing.

In no well has it been found practicable to drill a deep boring of the same diameter throughout. Through the incoherent deposits of the Pleistocene the bore is relatively large—possibly 10 or 12 inches in diameter—and casing of this size is driven firmly into the underlying rock to shut off all surface and drift waters. In a few wells Pleistocene gravel, mingled with drillings from lower horizons, has indicated that this work was not effectively done. Changing the drill to one of smaller diameter, the driller proceeds with the work until rock so incoherent or fissile, is reached that it caves into the boring. The only remedy is to case this portion of the shaft. The method of inserting the casing is described by Mr. Seth Dean[1] in his description of the Glenwood well, as follows:

[1]Proc. Iowa Civ. Eng. and Survey. Soc., 1895, p. 36.

"On the lower end of the pipe a cast-steel shoe with a cutting edge was fitted, the outside diameter of the shoe being a little larger than the coupling bands that connected the joints of the pipe, so as to give clearance room. Fitted in this way it was possible to drive a line of pipe through most of the strata after they had first been pierced by the drill, the shoe cutting out a portion of the rock somewhat in the manner that a carpenter enlarges a hole in a piece of wood with a gouge. When the harder beds of limestone were struck, the pipe was raised a few feet with jacks and the hole enlarged by what is known as an expansion reamer, a tool so constructed as to pass down inside the casing and open when it meets with the resistance afforded by the rock bed under the pipe. When the friction of the mass of earth and shale against the sides of the pipe became so great that it could not be driven farther without danger of crushing or collapsing, it was bedded firmly in some stratum of rock and a pipe of smaller size was inserted inside this and driven in the same way. The rate of progress made in driving pipe was, of course, dependent on the nature of the material being worked. Sometimes in soft shales the weight of the pipes alone was enough to sink it, and at other times six hours' driving would not settle it more than three or four inches."

FINISHING WELLS IN SAND.

BY O. E. MEINZER.

INCRUSTATION OF SCREENS.

Throughout northwestern Iowa and adjacent portions of Minnesota and South Dakota the majority of drilled wells end in sand belonging either to the glacial drift or to the Cretaceous system. The successful finishing of these wells is perhaps the most important problem in connection with water supplies in this area. Most of them are two inches in diameter, and the well casing is made to serve also as the pump pipe. The sand rises with the water so persistently that it is found necessary to put a screen or strainer at the bottom of the casing to shut out the sand while admitting the water. Various types of screens are in use, but the common type for wells of small diameter consists of a perforated iron pipe surrounded by a brass gauze of fine mesh, the whole inclosed in a perforated jacket to protect the gauze. The screen is small enough to be let down inside the casing.

Wells finished in this manner prove satisfactory for a time, but in the course of a few years the yield diminishes and eventually almost no water can be obtained. When the screens are removed, they are found to be effectually sealed by a coating of silt, etc., firmly cemented into a hard, impervious mass. The cost of a screen is not great, and the substitution of a new one for the old every few years would not be a serious matter were it not that the removal of the old screen is attended by great difficulties. In many instances the coating of cemented silt becomes so thick that the screen can not be withdrawn on the inside, and it is then necessary to pull up the entire casing in order to remove it. The labor and difficulty involved in this process is considered by many drillers to be equivalent to that of sinking a new well. Moreover, the rusted casing is liable to break, or the hole may cave, and the well is then usually lost.

The clogging of the screen has been found to be so great a nuisance that in many localities nearly all drilled wells have been abandoned, and shallow sources again used. Especially has this been done in the recent years of abundant rainfall following a series of dry years in which many of the drilled wells were sunk. The aggregate cost of the wells which have thus been abandoned in this region amounts to hundreds of thousands of dollars; furthermore, the return to shallow wells is not a solution of the problem. Recognizing the magnitude of the difficulty, the writer has investigated the entire matter, with a view to finding a practical remedy.

In order to ascertain the composition of the incrustant and the chemical changes involved in the incrusting process, a typical two-inch well was selected, from which a screen of the ordinary construction, coated with the usual hard, dirty-gray substance had recently been removed. Both the water from this well and the incrusting material were analyzed. The data are presented below.

The well was owned by George Clynick, and was located in the SW. 1/4 sec. 33, T. 104 N., R. 29 W., in Martin county, Minnesota. It was drilled in 1899 to a depth of 70 feet, with a diameter of two inches. It yielded "all that the windmill could pump." Its head was 13 feet below the surface. The material penetrated in drilling was (1) blue clay, (2) bluish white sand, at first very fine, but changing into coarse grit, in which the well ends. The well was finished with an iron casing, ending with a screen of perforated galvanized iron pipe surrounded by a brass gauze, the whole being surrounded by a perforated brass sheath. The screen is three feet long and about one inch in diameter, and the length of time required for it to become effectually clogged was reported to be about five years.

Analysis of water of Clynick well, Martin County, Minnesota.

[Analyst: H. A. Whitaker, chemist, Minnesota State Board of Health, July, 25, 1907]

	Parts per million
Silica (SiO_2)	24
Iron (Fe)	2.6
Calcium (Ca)	140
Magnesium (Mg)	54
Sodium and potassium (Na+K)	22
Carbonate radicle (CO_3)	0.0
Bicarbonate radicle (HCO_3)	259
Sulphate radicle (SO_4)	389
Chlorine (Cl)	4
Nitrate radicle (NO_3)	1.5
Free ammonia	2.0
Free carbonic acid (CO_2)	54
Total solids	772

Analysis of the material which incrusted the screen.

[Analyst: R. B. Dole, United States Geological Survey, Sept. 26, 1907.]

Clay, sand, silica, etc.	56.0
Oxides of iron and aluminum	2.8
Calcium	13.0
Magnesium	1.3
Sodium and potassium	.7
Carbonate radicle	20.6
Sulphate radicle	.4
Chlorine	.1
Phosphate radicle	.0
Organic and volatile matter	5.3
	100.2

To the above analysis the following note was added:

Of the 56 per cent comprising the silica and insoluble silicates, only 31 per cent is volatilized by hydrofluoric acid, showing that there is probably considerable clay present. Indeed, clay, sand, and carbonates of calcium and magnesium comprise 90 per cent of the deposit. The probable presence of sand particles is indicated by the fact that the substance was gritty when first pulverized, and required two days grinding to reduce it to a powder fine enough for analysis.

The principal cementing substance is probably calcium carbonate precipitated from the water. The sand, silt, and clay are packed about the screen by the inflow of water, and the interstices are then filled with calcium carbonate and other materials. Thus, the whole becomes a nearly impervious sheath which shuts out the water.

Whenever, in any well, the pump is operated, the weight of the water column is decreased by the removal of water, and it is this diminution in pressure that causes a new supply of water to flow through the screen into the well. The reduction of the pressure may allow a portion of the carbon dioxide to pass out of solution, disturbing the equilibrium between the free carbon dioxide and the bicarbonate radicle and effecting partial decomposition of the latter substance. As a result of this reaction, calcium carbonate is probably precipitated and is incorporated in the incrusting material. Only minute quantities of calcium carbonate need be deposited in order to effect the sealing of the screen in the course of several years. Possibly precipitated iron also adds to the cementing material. Electrolysis may occur between the brass and the iron portions of the screen, but the fact that some screens made entirely of brass have become incrusted as readily as the ordinary brass and iron ones seems to make this explanation inadequate. If the diagnosis given is correct, the process does not depend chiefly on the nature of the screen, but on changes which unavoidably accompany the withdrawal of water from the well, and hence the remedy must be sought along mechanical rather than chemical lines.

REMEDIES FOR INCRUSTATION.

A study of the mechanical aspects of the problem makes it possible to put forth some suggestions which, if followed, should prove of value by diminishing the annoyance and expense connected with wells finished in sand.

LARGE DIAMETERS.

Two-inch wells should not be drilled in regions where the screens become incrusted. For farm purposes wells from four to six inches in diameter can generally be finished successfully with open ends, whereas it is invariably necessary to put screens into those only two inches in diameter. The explanation is simple. With a given rate of pumping, the upward velocity of water in a well varies inversely as the square of the diameter, and the capacity of a current to lift solid particles varies as the sixth power of the velocity. Consequently, sand that will cause no trouble in a large well will persistently rise in a small one if it is not screened. Practically the effect is probably even greater than the above ratio indicates, because in the wells of large diameter the inflow and upward velocity are nearly constant as long as the rate of pumping is kept constant, whereas in a well of small diameter the casing usually serves also as the pump pipe, and hence the upward current is not uniform, being zero during the downward stroke and varying from zero to a maximum and back to zero during the upward stroke. In general, it will be found more satisfactory and ultimately more economical to drill wells at least four inches in diameter than to put down the small two-inch tubulars.

It is important, however, to understand that the finishing of sand wells with open ends should be attempted only where the rate of pumping is to be slow—for example, in farm wells where windmills are used. As a rule, wells furnishing water for public supplies and others pumped by steam or gasoline engines should be provided with screens. A number of sand wells used for public supplies in this region were finished without screens, and nearly all of these have given trouble. The sand rises with the water, cutting out the pump valves, clogging the mains, and filling the wells to such an extent that the supply is greatly diminished or the wells are totally ruined.

Drilled sand wells of large diameter invariably require screens if the rate of pumping is to be rapid, and some require them even though the rate of pumping is slow. Wherever there is danger that the sand will rise, it is the part of discretion to put in a screen. It should be remembered, however, that a five-inch well with a screen is much better than a two-inch well similarly finished. In the latter the screen must of necessity fit snugly into the casing, and when it becomes incrusted it may be impossible to pull it up, thus causing much trouble and frequently making it necessary to pull the entire casing. In a five-inch well, on the other hand, a small enough screen can be used so that there will be no difficulty in removing it. Experience shows that it is poor economy to drill two-inch wells.

ENDING IN A COARSE LAYER.

The glacial deposits, in which many of the wells under consideration end, are irregular and may alternate rapidly from fine sand to coarse gravel. It is a matter of great importance to finish a well where the material is coarsest. Drillers understand the significance of this but are not always successful in practice. As a rule the coarsest part of a sand and gravel bed is at the bottom, but this is not invariably so.

DRIVING TO THE PROPER DEPTH.

Commonly a thin layer of "hardpan" lies at the contact between a bed of clay and a deposit of water-bearing sand and gravel. Frequently there is difficulty in driving the casing through the "hardpan," and hence it is often allowed to stop above this hard layer or to fit only loosely into it. If a screen is inserted, it is somewhat smaller than the casing and may sometimes be projected through the hole in the "hardpan" and into the water-bearing sand. This is a careless method of finishing a well. The clay is liable to be washed down and to come in contact with the screen, thus greatly hastening the clogging process; or if the well has an open end the caving of the clay may obstruct the entrance. Not infrequently wells are ruined by neglect of the driller in this respect. Whether they are to be finished with or without a screen, it is important to have the casing driven completely through the cap of "hardpan" and down into the coarsest part of the sand or gravel.

DEVELOPMENT OF GRAVEL SCREENS.

Glacial deposits and to some extent also Cretaceous strata are poorly sorted, fine sand and coarser grit being more or less mixed together. When a well is to be finished in one of these deposits it should be pumped for a protracted period in such a manner as to remove the fine silt and leave a natural screen of coarser material. This frequently makes it possible to finish the well without a screen where otherwise one would have been required, but it should be done even where a screen is to be inserted. Proper treatment in this respect requires patience and skill but it undoubtedly results in superior wells.

The process of developing a natural screen is sometimes supplemented by introducing into the well a quantity of gravel or crushed tile of proper coarseness. This method has proved successful with drillers who are willing to devote sufficient time and effort to it, and often makes it possible to finish a well without putting in an ordinary screen.

INDEPENDENT PUMPS.

As has already been explained, in two-inch wells the casing usually serves also as the pump pipe, a device that produces more or less unsatisfactory results. The water must enter as rapidly as it is drawn up by the pump. This gives an intermittent and irregular current into the well and increases greatly the danger of drawing up sand. Even where a screen is used, this arrangement is liable to force fine silt through the meshes or to break holes in the screen, and the great reduction of pressure in the well on the upstroke probably increases the precipitation of calcium carbonate. When the yield is small or when the inflow of water is obstructed by the incrusting of the screen, pumping becomes difficult and the wear and tear become great. An independent pump hung in a well of adequate diameter involves some additional cost but is much more satisfactory.

FREQUENT REMOVAL OF SCREENS.

Much of the difficulty with the screens could be avoided if they were renewed more frequently. A screen which is left in the well until it has become so completely sealed that its removal is absolutely necessary is not only practically useless for a long time before its removal but is also liable to be so thickly coated that it can not easily be withdrawn.

SUMMARY.

Only wells of large diameter (four inches or more) should be drilled. Care should be taken to drive the casing through the cap of "hardpan" and through any beds of quicksand which may exist to the coarsest portion of the deposit. The fine sand should then be removed by protracted pumping and a natural screen of coarser sand or gravel developed. Gravel of the proper coarseness may also be introduced into the well to be added to the natural strainer. If the water is to be drawn at a slow rate and an independent pump is used, it is generally not necessary to put on a metal screen. If, however, the water will not become clear and the sand persists in rising, a screen should be inserted and tightly attached to the bottom of the casing. It should be considerably smaller than the latter so that it can be easily removed when it has become incrusted. As soon as the yield of the well shows distinct signs of reduction, the screen should be drawn up and cleaned or else replaced by a new one.

MUNICIPAL AND DOMESTIC SUPPLIES

POLLUTION.

SOURCES.

From the sanitarian's point of view waters from wells tapping the deep-lying sandstones or the deep sand layers of the drift may be considered above suspicion if the wells are protected from the access of surface water from their immediate vicinity. The diseases ordinarily communicated by water are bacterial in origin—that is, the immediate causes are microscopic single-cell plants, called bacteria, which come from previous cases of typhoid fever or other diseases and find their way into river or well water through sewage or surface water. According to present standards of sanitation it may be definitely stated that the waters of rivers flowing through moderately well inhabited regions and having the usual number of towns and villages along their courses are unsuitable for drinking or general domestic use without being purified. The experience of a number of Iowa towns, such as Waterloo (p. 308) proves that typhoid bacilli in river water may pass the guard of filtration plants and cause serious epidemics unless the process of fitration is constantly maintained at its highest efficiency. That springs rising from creviced and cavernous bedrock which receives the drainage from adjacent cities may be polluted has been recently shown at Cedar Falls (p. 306). Even the purest artesian waters from wells thousands of feet deep are liable to become contaminated by shallow ground waters if such are allowed to enter through corroded casings. Epidemics of typhoid fever at Clinton, in the shops of the Chicago & North Western Railway, and at Glenwood, in the Asylum for Feeble-minded Children, were caused by leakage from adjacent privies and drains into deep artesian wells.

TOWN WELLS.

Shallow dug wells, walled as they generally are by brick or tile, that permit the inflow of water from top to bottom, are usually unsafe in a town or even in the country unless they are well protected from contamination by kitchen or household waste, privies, drainage from stable yards, and all similar sources of pollution. Though the water of any one such well may be used for a long time without serious results, it is nevertheless a constant menace to life and health. Infectious material is likely to enter it at any time that it may be brought into the neighborhood. In towns the danger attending the use of well water is undoubtedly in direct proportion to the prevalence of privy vaults, cesspools, badly drained streets, and decaying garbage. All persons are not equally susceptible to disease, and it is not to be taken for granted that because a family or a certain number of persons have long used the water without ill effects others may do so with impunity.

Some wells given in this report as the sources of municipal supplies belong to the class of shallow wells just described. They are dug and walled wells or driven wells in river bottoms or in superficial sand layers. Nothing protects them from the surface water in their immediate vicinity. The surrounding land should be as scrupulously protected from human habitation, factories, and other sources of contamination as the collecting ground of lakes and artificial reservoirs whose waters are used for municipal supplies. The underflow where the wells are located should be toward the town, not from it toward the wells. If the town is on a river, the wells should be above and not below the town. There should be no higher inhabited land in their immediate vicinity. In the course of this investigation evidence has not been wanting that such simple and reasonable provisions as above suggested have not received attention in some towns that derive their water from wells of this character.

The sanitary character of well water is improved in proportion to the exclusion of surface water from the immediate vicinity, because water coming through earth or sand for considerable distances is freed from organic matter and bacteria by fermentation and filtration. Herein is the advantage that the deep well has over the shallow one. Deep wells derive their waters in most places from the deeper sand layers, sand rock, and other porous filtering material. The water they supply fell upon areas at considerable distances and reached the wells through long stretches of natural filter. For example, most of the water in the deep-lying sandstones in Iowa fell in Wisconsin and Minnesota and reaches the consumer only after passing through many and in some places several hundred miles of sandstone filter. Whatever organic matter and living organisms the water originally took up at the surface where it fell have long since been destroyed and removed.

Fortunately, most wells which supply Iowa cities are of this character and derive their water from far-removed collecting grounds. They are generally driven wells, or bored or drilled and cased. In such wells water can enter only at considerable depths, in the shallower ones only near the bottom, and even if it fell near the well it could enter only after filtration through many feet of earth. It must be said, however, that some town wells are bored and walled with sewer or fired tile placed loosely one upon another, and in such cases water may enter at any point, dependent only on the weather and the height of the water table.

The experience of sanitarians is in harmony with these considerations. The number of bacteria in well water decreases as surface drainage is cut off. The pathogenic species are absent from the water of properly constructed deep wells, and in some very deep wells bacteria are totally absent. If a town or a home draws its water supply from a deep cased well in thorough repair, having its footing in some large source of water, it is probable that the water as it comes from the well is free from contamination, and its wholesomeness as it reaches the consumer depends only on the character of the reservoirs and the conducting system. It is, of course, absolutely necessary that all storage tanks should be protected from dust, animals, and any other sort of accidental or intentional contamination; that all underground conducting pipes should be of nonporous material, and that all joints should be water-tight.

FARM WELLS.

BY O. E. MEINZER.

The most common type of well in the western part of the state is the shallow bored well. It is made with a machine called a "well auger," is generally between 1½ and 3 feet in diameter, and is cased with wood or some other material that will admit water freely from all levels. In this way a great surface admitting water to the well is made to compensate for the low pressure of the water and the poor conductivity of the water-bearing material. Since the water comes from so near the surface it can easily become polluted, and care should be taken to have everything which might produce contamination removed from the vicinity of the well and from the ground that drains toward it. Unfortunately such precautions are not usually taken. While some householders are to be commended for carefully protecting their wells, the majority are guilty of inexcusable negligence and many seem to utterly disregard the sanitary aspects of their water supply.

The well is generally located on low ground and frequently in a favorable position to receive the drainage from the barnyard and outhouses. This is because the farmer wants his house and barns on high ground and yet as near the well as possible. On many farms, too, it is located in the barnyard and is surrounded by manure. The upper part of the casing in many wells is decayed and the ground where the well is situated is on a level with the rest of the barnyard, so that seepage from the yard inevitably enters the well. Many farmers cover their wells in the autumn with manure to prevent the pumps from freezing, and this is not always removed in the spring. Thus some of the matter leached from the manure by the rains is washed into the wells. Some wells, also are situated on ground so low that they are flooded in heavy rains.

In a few wells clay or concrete tiles are employed for casing, but more commonly boards are used. The wood is most subject to decay near the surface where it is alternately wet and dry; farther down in the well, where it is more constantly submerged and thus protected from the atmosphere, it decays less rapidly. Consequently the wooden casing in many wells is partly removed near the top, giving excellent opportunity for surface wash and also for small animals to enter. Drillers and borers whose business it is to clean out these wells declare that it is common to find decaying mice, rats, rabbits, and other small animals in wells which are at the time being used for domestic purposes, and that many families are using water which contains so much putrid matter that it is nauseating to one who has not become accustomed to it. These conditions are due largely to carelessness and could easily be prevented by the application of ordinary good judgment and by a regard for ordinary cleanliness.

MINERAL CONTENT OF THE WATER.

MINERALS IN RIVER AND WELL WATERS.

Compared with waters of the northern and eastern states, all Iowa waters are highly mineralized, or, as it is commonly expressed, they are hard waters. The state is deeply covered by drift and soil, composed mostly of finely divided material which is highly calcareous and contains considerable amounts of calcium sulphate and other more soluble compounds. The rainfall comes into intimate contact with this material, and that which becomes ground water, from which wells are supplied, must pass for long distances through it, giving the water great opportunity to take up mineral matter. The amount of run-off from igneous rock surfaces is practically nothing in this state and that from bare rock surfaces of any sort is insignificant. Only very small superficial sand areas in the state take up the rainfall and transmit it as soft water to wells or to rivers. The deep rich soil also contributes indirectly to the mineralization of water. Nearly the whole area is covered with vegetation of some sort and the soil contains large amounts of decaying vegetable matter. An unusual amount of carbon dioxide is thus supplied to the water at the surface, which enables it to dissolve large amounts of calcium and magnesium carbonates.

The waters of both rivers and wells are considerably more highly mineralized than those of the eastern states, and three of the largest Iowa rivers contain very much larger amounts of mineral matter in solution that the average of the rivers of the whole continent. The average total solids of Des Moines, Cedar, and Iowa rivers, as determined by analyses by the United States Geological Survey[1] extending from September, 1906, to September, 1907, is 262 parts per million, whereas the average of the river waters of the continent is stated to be 150 parts per million.[2] The average mineral content of these three rivers and that of the best wells of moderate depth in the regions where the rivers take their rise are remarkably alike in both the amount and character of their total solids. The same general agreement is found between the mineral matter of the rivers and that of the best deep wells. For purposes of comparison, there are given below the analyses the three rivers already named, the average analyses of 12 of the best wells of moderate depth, for the most part in the northern and eastern portions of the state, and the analysis of a representative of the best deep wells, that of the Eighth Street city well at Dubuque, which has a depth of 1,200 feet and foots in the sandstones underlying the Saint Lawrence formation.

[1]Dole, R. B., The quality of surface waters in the United States: Water-Supply Paper, U. S. Geol. Survey No. 236, 1909, pp. 116-119.

[2]Chamberlain, T. C., and Salisbury, R. D., Geology, 2d ed., vol. 1, p. 108.

Comparison of analyses of well and river water in Iowa.

(Parts per million.)

	Three rivers	Twelve wells	Deep well		Three rivers	Twelve wells	Deep well
SiO_2	18	13	12	Na	14	9.7	7.0
Fe	.20	.25	.00	HCO_3	212	273	284
Al	----------	1.0	.5	SO_4	46	26	16
Ca	52	62	54	Cl	4	5	5
Mg	18	25	32	Total solids	262	279	268

The total solids for the rivers include only the dissolved mineral matter. If the suspended matter is added, the total matter carried by the river waters is 553 parts per million.

The averages of the analyses of the river waters represent samples taken as follows: Cedar river at Cedar Rapids, dissolved solids 228; Iowa river at Iowa City, dissolved solids 247; and Des Moines river at Keosauqua, dissolved solids 312. The dissolved solids of the three rivers are not very different in amount and closely agree in their composition, which is similar to that of the solids of the best well waters. The three rivers show considerably smaller amounts of dissolved mineral matter than the water of Missouri river on the west, as might be expected, for the Missouri derives a large portion of its water from the northwest and to a large extent from the so-called alkali regions. The Missouri shows at Florence, Nebraska, 454 parts of total solids.[1] On the other hand, the solids of the three Iowa rivers are greater than those of the upper Mississippi, which comes largely from Minnesota and Wisconsin, where much of the collecting ground is covered with sand and sandstone. The Mississippi near Moline, Illinois, shows 179 parts of dissolved solids.[2]

The general impression that river waters are soft and well waters are hard is in a general way true. However, no sharp line of demarcation can be drawn, at any rate in northeastern Iowa. The very best well waters from both shallow and deep wells in the northeastern part of the state, which is the main collecting ground for the river waters, show about the same

[1] Water-Supply Paper U. S. Geol. Survey No. 236, 1909, p. 78.
[2] Water-Supply Paper U. S. Geol. Survey No. 239, 1910, p. 81.

mineralization as the river waters. These wells are, however, comparatively few, most wells in this same region showing solids ranging from 300 to 500 parts per million.

EFFECT OF MINERALIZED WATERS ON HEALTH.

Though the water of a considerable number of Iowa wells contains as low as 280 parts per million of mineral matter, and most of those in the northeastern part of the state contain less than 500 parts, the great majority of well waters in the whole state contain 400 to 2,000 parts of solids. Several contain 2,000 to 5,000 parts and a few 5,000 to 9,500 parts. It is a matter of especial interest that several towns have for a number of years used as city supplies waters containing 2,000 parts per million of solids. Though waters containing as much mineral matter as 2,000 parts per million are clearly unsuitable for many purposes in the untreated condition, such as for boilers and for laundry purposes, so far as is known no serious effects on the health of the people can be traced to the use of such waters. At present there seem to be no generally recognized standards by which to judge of the fitness of hard waters for drinking. The only limit in the use of hard water in Iowa is the unpalatableness caused by the presence of considerable amounts of chlorides and sulphates. It is a curious fact that although people as a rule will not tolerate a distinct taste in a water supply for ordinary daily use, at watering places they will readily drink large quantities of similar water containing even more of the constituents which at home they consider distinctly objectionable.

Apparently waters containing more than 2,000 parts of mineral matter are unpalatable, and this amount may be taken as the maximum allowable in a water supply for city use and particularly for drinking. So far as general observation and the testimony of physicians are concerned, this limit seems practical and safe, though it can not be confidently asserted that the use of such waters for a few generations might not be attended with injurious results.

Standards of other regions, particularly of those where the surface rock is granite or sandstone, can not be applied in judging Iowa waters. The Iowa standard must depend on what sort of water can actually be secured and on experience in the use of the waters of the state. Of course, the standard for a boiler water or one for any other industrial purpose must be different from that of a water for a town supply. The latter must be obtained in large quantity, must serve for a multitude of domestic and industrial purposes, and must have a high degree of organic purity, if it is not to be filtered Much mineral matter may be tolerated for the sake of bacteriologic purity. Therefore, a city in Iowa with a water supply which is organically pure and which contains less than 400 parts per million of solids is very fortunate. An organically pure water containing less than 600 parts may be considered good, one with less than 1,000 parts fair, one with less than 1,500 parts tolerable, and one with 2,000 parts usable if no better can be obtained. Above 2,000 parts the water may be considered unpalatable, and that of private shallow wells would be preferable. Of course, these statements apply to the average hard water, in which the excessive solids are composed largely of calcium, magnesium, sodium, and sulphates.

EFFECT OF MINERALIZED WATERS ON WELL CASINGS.

CORROSION.

Many waters act vigorously on iron in the cold, and many well casings in Iowa have been rusted through in a few years. At Cedar Rapids a wrought-iron casing was corroded to a perforated shell in about five years. At Grinnell the water of well No. 1, containing 2,000 parts per million of mineral matter, rusted through the casing in about eight years. In many other wells the waters have become progressively and notably more highly mineralized, and though this may be due to other causes, the chief cause is most probably the perforation of the casings and the access of the upper hard waters that the casings were designed to shut out. Deep well No. 2 at Centerville, for instance, was drilled to a depth of 2,054 feet in 1904. The following are the results of four analyses in terms of total solids, at intervals of about a year:

Total solids in water in well No 2 Centerville, Iowa.

	Parts per million
September 18, 1905	1,228
September 8, 1906	1,637
November 26, 1907	1,930
September 9, 1908	2,594

The rusting out of casings must be regarded as one of the most serious difficulties in maintaining a supply of artesian water, and how to prevent it or retard it so as to lengthen the life of wells is a problem which merits the most earnest consideration. After a casing has become weakened by corrosion and has become packed in the boring by sediment derived from the walls or deposited from the water it is very difficult or impossible to withdraw it so as to replace it by a new tube. The only remedy in such instances is to put a smaller tube within the old one, thus reducing the effective diameter of the well.

SOFT-STEEL VS. WROUGHT-IRON TUBING.

At the present time soft-steel tubing, on account of its cheapness, has for most purposes replaced wrought-iron tubing. It is not easy to get wrought-iron tubing without a special order, and this has led to the casing of many wells with steel. Experience seems to show that this is a mistake. Wrought iron withstands the corrosive action of water much better than soft steel and it should always be preferred to steel for well casings.

Cast-iron tubing may yet be proved practical for casings. It has far greater resisting power than steel or wrought iron against the corrosive action of water, and it is considered the only suitable material for water mains and for sewer pipe inside of buildings.

In this connection the casing of well No. 4 at Grinnell is of peculiar interest. Several flows of highly mineralized waters are encountered above the New Richmond and Saint Peter sandstones, which furnish the main supply. After experiencing a good deal of difficulty due to the corrosion of casings and the caving of shale below the casings of the older wells, the city authorities determined to case the new well with cast-iron tubing to the depth of 1,700 feet, or to a point just above the Saint Peter sandstone. Owing to difficulties connected with reaming out the well the casing was finally put down only to 1,461 feet. It consists of six-inch heavy cast-iron tubing, the sections of which are closely joined together with wrought-iron couplings. No difficulty was experienced in lowering the casing. The well was completed in January, 1910, and has been in use since that date. So far as known to the writer there is no other cast-iron casing in the state and none of greater length than 200 or 300 feet in neighboring states. The experiment at Grinnell seems to demonstrate the practicability of lowering cast-iron casings of lengths as great as are likely to be desired.

As this enterprise has proved successful, it is likely to influence greatly the casing of wells in the future, and the cast-iron casing should be instrumental in prolonging the life of artesian wells in localities where upper waters cause rapid deterioration of ordinary casings. It is possible that it may extend the area of successful artesian wells in this state.

CAUSES OF CORROSION.

The cause of the corrosion of iron has in recent years been the subject of much research and not a little controversy. The work and discussion have centered around the question whether water and oxygen alone are able to produce corrosion, or whether carbonic acid or some other acid is necessary. No fewer than eight research papers have appeared on this subject in the last four years. Of these, one by Walker and others[1] and one by Tilden[2] sum up the results of the whole investigation and give all needed references.

PURE WATER.

It appears beyond a doubt from the work of Walker and his associates that pure water alone is able to dissolve iron in very small amounts. This is shown by direct experimental evidence, and it is fully in accord with the present ionic theory of the solution of metals. Water is to an exceedingly small degree an electrolytically dissociated substance, its ions being

[1]Walker, W. H., Cederholm, A. M., and Bent, L. N., The corrosion of iron and steel: Jour. Am. Chem. Soc., vol. 29, 1907, p. 1251.

[2]Tilden, W. A., The rusting of iron: Jour. Chem. Soc. Trans., vol. 93, pt. 2, 1908, p. 1356.

$\overset{+}{H}$ and $\overset{-}{OH}$. Iron, like other metals, has its own particular tendency to go into solution in the form of ions — that is, its solution pressure, and this pressure is slightly greater than that of hydrogen. Very slowly and to a very limited extent iron goes into solution in pure water as positive ions, $\overset{++}{Fe}$, while hydrogen is forced out of solution, its positive charge going to neutralize the negative charge of the undissolved iron. Walker could easily detect the iron thus dissolved by testing with potassum ferrocyanide or potassium sulphocyanide, after evaporating the solution to small volume.

Water thus acts much like an acid, but its action is exceedingly slow, and an equilibrium is soon reached when the action ceases unless oxygen is present to oxidize the iron and cause its removal from solution by precipitation. As a matter of fact, carbonic acid is present in most natural waters as free acid, or as the bicarbonate. The free acid is partly dissociated into its ions, $\overset{+}{H}$ and $\overset{-}{HCO_3}$. The number of hydrogen ions that can thus occur in natural waters very greatly exceeds the number due to the dissociation of water itself, and under similar conditions the rate of solution of the iron will be proportional to the number of hydrogen ions. The iron dissolved under these circumstances may be regarded as being present in the water as ferrous bicarbonate, $\overset{++}{Fe}$, $2\overset{-}{HCO_3}$. In the presence of oxygen the iron becomes quickly oxidized to the ferric condition, hydrolysis occurs, and the iron is precipitated as a hydrated ferric oxide. If the oxidation takes place as fast as the iron is ionized and at once, the apparent result of the corrosion may be a coating of more or less adherent rust. When hydrolysis occurs hydrogen ions are again released equivalent to the negative ion of the carbonic acid, and thus the same molecule of carbonic acid may cause the corrosion of its equivalent of iron over and over again.

Nearly all Iowa waters contain 5 to 25 parts per million of free carbonic acid and large amounts of bicarbonates, which gradually give off in the cold one-half of their carbonic acid on standing, with the precipitation mainly of normal calcium carbonate. The decomposition is of course greatly accelerated when the water is boiled. The free carbonic acid that may be derived from this source varies in Iowa waters from 100 to 200 parts per million. In view of the above statements it may be readily understood why boilers rust more at some points than at others. At the water level the metal may be acted upon by the carbonic acid in the water and by the dissolved oxygen at the surface of the water. At the intake, where much corrosion occurs, carbonic acid is being rapidly set free from the bicarbonates, and neither it nor the oxygen has yet been expelled from solution by boiling.

ACID WATER.

Hydrogen ions, which may be regarded as the main initial cause of the corrosion of iron in boilers, are not alone due to the slight dissociation of water or to carbonic acid. Salts containing a weakly basic metal or a weakly acid radicle or both undergo to a greater or less extent what is known as hydrolysis: that is, water reacts with the metallic radicle forming an oxide or a hydroxide and hydrogen ions, or, what amounts to the same thing, free acid. Salts of copper, aluminum, and iron offer good examples. A solution of copper sulphate is always faintly acid, its hydrolysis taking place thus:

$$\overset{++}{Cu}, \overset{=}{SO_4}+2\overset{-}{HO}, 2\overset{+}{H}=Cu\ (OH_2)+2\overset{+}{H}, \overset{=}{SO_4}$$

The hydroxide may be nearly insoluble and the main portion of it may form a precipitate, it may remain in true solution, or may assume an intermediate state known as the colloid condition. In the cases of iron, copper and aluminum the last is probably true. However, in any case a small part goes into true solution and is to some extent ionized. The hydroxyl ions thus accumulate and react with the hydrogen ions to form water; or, to take another view, they force back the dissociation of the water, thus bringing the reaction to a state of equilibrium. Some sulphuric acid, however, remains in solution and is highly ionized. Its hydrogen ions escape as neutral hydrogen and, as with carbonic acid, their place is taken by the ions of iron from the boiler or from other iron that may be in contact with the solution. The iron may be oxidized to the ferric condition and precipitated, its place being taken by fresh iron ions.

From recent work it appears that salts of the alkali metals and strong acids which undergo no hydrolysis and can not form hydrogen ions do not greatly influence the corrosion of iron. Heyn and Bauer[1] found that the rusting if iron at room temperature is in general greater in distilled water than in dilute solutions of simple electrolytes. With increasing concentration, however, the rusting increased somewhat and then decreased. In general, salts at their maximum of activity caused more rusting than distilled water, but contrary to popular opinion solutions of potassium, sodium and calcium chlorides, sodium and potassium sulphates, and sodium bicarbonate showed less activity at their maximum than distilled water. With certain salts corrosion decreased very rapidly with increased concentration and soon ceased altogether. Salts of ammonium and particularly those of phosphoric acid showed high corrosive power, probably owing to their hydrolysis.

The salts just enumerated as having less corrosive action than distilled water include most of the readily soluble salts usually calculated as possibly present in natural waters. From the above experiments corrosion at ordinary temperature can not apparently be ascribed to them, and this conclusion is in harmony with theory, for they can form no hydrogen ions. It is a common observation, however, that metals in contact with some chemical substances, particularly common salt, corrode more rapidly when exposed to the air. This corrosive action is probably to be ascribed to the fact that such chemicals are usually hygroscopic, and the corrosion is probably due to the water which the salt takes from the air and holds in contact with the metal.

ALKALINE WATER.

As already intimated hydroxyl radicles counteract or neutralize hydrogen ions and thus inhibit corrosion. Alkaline waters do not corrode iron. Ordinary corrosive waters lose that power when treated with sufficient sodium hydroxide or any other

[1]Heyn, E., and Bouer, O., Mitt. K. Prufungs-Anstalt. Gross Lichterfelde, vol. 26, 1907, pp. 1-104.

chemical which when highly dissociated gives OH radicles, such as lime or soda ash. The action of the latter is to be ascribed to its hydrolysis, which gives highly dissociated sodium hydroxide:

$$2\ \overset{+}{Na},\ \overset{=}{CO_3}+\overset{+}{H},\ \overset{-}{OH}=\overset{+}{Na},\ \overset{-}{OH}+\overset{+}{Na},\ \overset{-}{HCO_3}$$

Even sodium bicarbonate is slightly alkaline—that is, it dissociates to a small extent into highly dissociated sodium hydroxide and very slightly dissociated carbonic acid, which can, therefore, give few hydrogen ions in comparison with the sodium hydroxide. Of course, if a water is heated any acid carbonate the water may contain is changed into the normal carbonate, which in turn will dissociate as given in the equation. Moreover, the free carbonic acid set free when the normal carbonate is formed decomposes at the boiling temperature into water and carbon dioxide (which escapes), thus making impossible the formation of hydrogen ions from its own dissociation as would occur in the cold. Therefore it is evident that water containing relatively large amounts of alkali carbonate can not be corrosive.

INDUSTRIAL SUPPLIES

IMPORTANCE.

Every town large enough to have a water system contains some industry dependent on a suitable supply of water. Steam-power plants are of primary importance, and water that can be used in boilers must be obtained for them. Many towns have steam laundries, artificial ice plants, tanneries, dye works, starch works, sugar refineries, and many other industries which demand water suitable for their particular needs. These needs can not be discussed in detail. Suffice to say that all desire the clearest and softest water they can get. However, on account of the universal need of boiler water, it seems desirable to devote some space to its consideration.

BOILER WATER.

QUALITIES OF GOOD BOILER WATERS.

Water may affect the boiler in which it is used in two chief ways—by the deposition of foreign matter (scale) and by direct corrosion of the metal. A good boiler water is one which will not foam, which will deposit the minimum of scale or sediment and which will not to any considerable degree corrode the metal of the boiler. The characteristics of a good boiler water are too many to mention in detail, but the following are those of most practical importance: (1) It should be normal in the sense that it must contain only the substances ordinarily found in natural water. It should not contain iron salts in excess of a few parts per million and it should contain no free mineral acids. Water from a coal mine or from a shale bed may contain not only iron salts but also free sulphuric acid, due to the oxidation of iron pyrite and other sulphides. The same may be true of water collected from ground near a coal yard or near heaps of ashes and cinder from soft coal. (2) It must contain as small a total amount of mineral matter as is practicable to find in a natural water in the locality, and its incrusting solids should be relatively low. (3) It should contain only small amounts of suspended matter, organic matter, oil, or any other foreign substance of similar nature.

As already stated, the chief difficulty in the use of Iowa waters is their high content of mineral matter, largely of the incrusting sort. On that account they appear at a disadvantage as boiler waters when they are compared with ideal standards. It may be interesting to compare them with what is perhaps the best practical standard, that of the committee on water service of the American Railway Engineering and Maintenance of Way Association.[1] This standard is given in terms of incrusting solids and, stated in round numbers in parts per million, is as follows:

[1]Proc. Am. Ry. Eng. and Maintenance of Way Assoc., vol. 5, 1904, p. 595.

Standard of quality of water.

Less than 90 parts per million	Good
90 to 200 parts	Fair
200 to 430 parts	Poor
430 to 680 parts	Bad
Over 680 parts	Very bad

This standard, in view of the actual conditions the country over and the effects of hard water, is to be taken as liberal in its allowance of incrusting solids. It applies to incrusting substances and not necessarily to corrosive ones. Though highly mineralized waters may in general be more corrosive, this action depends not on amount of matter in solution but mainly on its content of hydrogen ions under boiler conditions. Rated by this standard, probably practically none of the Iowa waters can be called good for boilers. A small percentage fall within the class "fair," but most of the best waters, even in the northeastern parts of the state, are to be classed as "poor." On the whole the deep well waters and those of most of the rivers and ponds must be regarded as being too hard to give the best boiler service, though many of them give good results when the boilers are properly managed.

BOILER SCALE.

DEPOSITION.

Nearly all Iowa well waters are acid to phenolphthalein—that is, they contain bicarbonates and from 5 to 25 parts per million of free carbon dioxide. On being exposed to the air, even without being heated, they lose carbon dioxide and precipitate normal calcium carbonate, usually colored by small amounts of iron hydroxide. The precipitation is due to the breaking up of the bicarbonate radicle $2HCO_3$, into $H_2O+CO_2+CO_3$; the CO_2 being evaporated and the carbonate radicle uniting with calcium to form calcium carbonate ($CaCO_3$), which is precipitated. Magnesium also is precipitated, but as a basic carbonate, which may possibly change to hydroxide in a boiler under high pressure. The magnesium hydroxide found in boilers may originate partly in this way and partly by the direct hydrolysis of its salts at the high temperature of the boiler. The mixture of calcium carbonate and magnesium basic carbonate or hydroxide thus formed, with small amounts of silica, iron, and aluminum hydroxides, settles ordinarily as a powder and does not alone form a hard scale. When, however, it is deposited in company with calcium sulphate, it forms the hardest and most refractory of all boiler scales, apparently uniting into a cement of stonelike texture and properties.

The deposition of calcium sulphate is slightly different. When a water containing the usual radicles is evaporated several compounds may be precipitated. If they were present in amounts proportional to their chemical equivalents the precipitation would occur approximately in the reverse order of their solubilities in hot water. This proportion is practically never realized, however, and, moreover, waters in boilers are rarely allowed to become concentrated enough between blowouts to precipitate more than one other compound, namely, calcium sulphate.

Calcium sulphate is only slightly soluble in cold water, the amount contained in water at saturation being about 2,000 parts per million. According to the determinations of Tilden and Shenstone, however, water when raised to the temperature attained in a steam boiler run at average pressure can retain only one-tenth of this amount, or about 200 parts of calcium sulphate. It follows that the calcium sulphate in many of the hardest Iowa waters would be precipitated in part if the water were not concentrated at all by evaporation, but only heated to the temperature corresponding to a steam pressure of about 150 pounds. The conditions are even more favorable to precipitation, because the temperature of the film of water in immediate contact with the boiler tubes and plates is probably raised to a temperature considerably higher than that corresponding to the steam pressure. The deposition of calcium sulphate is more rapid the more the water is concentrated by evaporation.

The calcium sulphate deposits in a more or less crystalline condition and cements together the particles of the other compounds of calcium and magnesium, forming in many cases a scale so hard that it can be removed only with some such instrument as a cold chisel.

When a hard water is used in a boiler, scale usually accumulates rapidly in the manner above indicated, and being a very poor conductor of heat it insulates the boiler metal from the water to be heated, thus greatly decreasing the efficiency of the boiler and increasing the consumption of fuel. The difficulties do not end there. Corrosion usually accompanies the formation of scale, shortening the life of the boiler. There is also a loss of time in cleaning and repairing the boiler. The residual water must be frequently replaced by fresh water, and the accumulated scale must be from time to time mechanically removed, which is a difficult and time-consuming operation and may cause considerable injury to the boiler. Even a loosely adhering scale or sediment in considerable amount is undesirable in a boiler. Not only is there loss of heat effect, but injector tubes become clogged and the sediment is likely to settle in a compact mass while the boiler is out of use. The plates may then be overheated when the fires are again started, and the breaking up of the mass and the sudden contact of hot plates and water may cause serious injury to the boiler or even cause it to explode. Numerous boiler explosions have been traced to this cause.

CHEMICAL COMPOSITION OF BOILER SCALE.

The most important scale formers are calcium and magnesium salts, but to these must be added silica and hydroxides of iron and aluminum, which are usually present in water in very much smaller amounts. Suspended matter, for the most part clays, may become entangled in the deposit so as to form a considerable portion of it.

The scale-forming power of a water is not proportional to its total solids, but rather to the sum of certain radicles which on boiling form sparingly soluble or insoluble compounds. It depends, too, on the amounts of other constituents in the water than those commonly called scale formers, and on the conditions, such as temperature and the frequency of blow-outs, under which the boiler is operated.

It is evident that boiler scale can not have a definite chemical composition, even if the same water is used, as its make-up depends on the conditions named. It is hardly necessary to state that the composition of the scales in different waters depends on the relative quantities of the scale-forming constituents in the waters.

Attempts to combine the sulphate radicle and the small amount of the carbonate radicle, as shown in analyses of scale, with the calcium and the magnesium, disclose a shortage in the acid radicles, showing that the greater part, and sometimes all, of the magnesium must be present in the form of oxide or hydroxide. In some analyses the acid radicles are not even sufficient to combine with the calcium. Iron, aluminum, and silica are present as oxides in small quantities. Doubtless the proportion of magnesium and calcium hydroxides increases with the temperature inside the boiler and it is questionable whether any magnesium carbonate remains stable in a high-pressure boiler.

PHYSICAL PROPERTIES OF BOILER SCALE.

Boiler scale may vary as much in its physical properties as in its composition, which depends on the nature of the mineral content of the waters from which scales are formed. The hardest scales are those containing large amounts of calcium sulphate cementing smaller amounts of calcium carbonate and magnesium oxide, and such scales are deposited from waters containing calcium largely in excess of the CO_3 radicle and large amounts of the SO_4 radicle. From such scales there are all grades to the powdery forms which scarcely adhere at all, yield to the touch, and may be washed from the boiler tubes with a hose. Soft scales do not greatly differ from the deposit formed when a scale-softening boiler compound is used. Some waters are said to carry their own boiler compounds, which means that the bicarbonate radicle is equivalent to or in excess of the calcium and magnesium. When they are boiled the carbonate radicle (CO_3) is formed and nearly all the calcium and magnesium are precipitated. Most of the Iowa waters of small mineral content belong to this class, but such waters heavily mineralized are not wanting. The two deep wells at Glenwood contain the bicarbonate radicle far in excess of the calcium and magnesium and their waters form no hard scale.

SCALE-FORMING POWER OF DIFFERENT WATERS.

As a rule chemists and engineers assume as scale-forming all calcium and magnesium carbonates and sulphates that can be calculated from the analytical data, together with silica and the oxides of iron and aluminum. Recently Herman Stabler[1] has proposed formulas by the aid of which may be calculated the corrosive action of a water, the amount of scale it is likely to form, and the amounts of chemicals necessary to soften it, without regard to any rigid assumption as to the chemical compounds that may exist in the water. His formula for calculating the amount of scale assumes that under ordinary boiler conditions all suspended and colloidal matter is precipitated; that all iron, aluminum, and magnesium are precipitated as oxides and all calcium to the full extent of its ability to combine with the carbonate, bicarbonate and sulphate radicles. Certain reactions are given, not as necessarily showing all that takes place, but as equations which express the known results of changes that occur within the boiler. They are as follows:

$2Al+3H_2O=Al_2O_3+6H.$

$Fe+H_2O=FeO+2H.$

$Mg+H_2O=MgO+2H.$

$Ca+CO_3=CaCO_3.$

$Ca+2HCO_3=CaCO_3+H_2O+CO_2.$

$Ca+SO_4=CaSO_4.$

$H+HCO_3=H_2O+CO_2.$

$2H+CO_3=H_2O+CO_2.$

The first three reactions are regarded as practically complete. The division of the carbonate and bicarbonate radicles between calcium and hydrogen and the division of the calcium between the carbonate and sulphate radicles are not definitely known, and they probably differ with different conditions of boiler operation. Formulas were constructed for maximum and minimum scale formation, but the differences were so small that they were rejected for one showing the average scale formation, as follows:

$$\text{Sc (scale)} = 0.00833\ \text{Sm (suspended matter)} + 0.00833\ \text{Cm (colloidal matter)} + 0.0107\ \text{Fe} + 0.0157\ \text{Al} + 0.0138\ \text{Mg} + 0.0246\ \text{Ca}.$$

The result is in pounds per 1,000 United States gallons of water, when Sm, Cm, Fe, and the other amounts represent parts per million found by analysis. The value 0.00833 is one part divided by 120 to convert parts per million to pounds per 1,000

[1]Engineering News, vol. 60, Oct. 1, 1908, p. 355.

United States gallons. The value 0.0107 for iron represents one part of iron calculated to FeO and divided by 120. The value for calcium is the mean of one part of calcium calculated to carbonate and one part calculated to sulphate, and the mean divided by 120. From this explanation the remaining values will be evident. The amount of calcium introduced into this formula should not be in excess of the calcium equivalent of the carbonate, bicarbonate and sulphate radicles—that is, Ca should not exceed $0.668CO_3+0.328HCO_3+0.417SO_4$, because such excess would not be precipitated.

The precipitated matter may be hard scale, wholly or in part, or it may be powdery sludge. The amount of hard scale that may be expected from a water can be calculated by means of the subjoined formula, which assumes that hard scale is composed of silica, calcium sulphate and magnesium oxide. All the silica and magnesium are precipitated, together with an amount of calcium dependent on the relative abundance of the chloride, sulphate and alkali metal radicles.

$$Hs\ (\text{hard scale})=0.00833\ SiO_2+0.0138\ Mg+(0.016\ Cl+0.0118\ SO_4-0.0246\ Na-0.0145K).$$

The first two values will be clear from the preceding explanation. The value 0.016Cl equals the calcium sulphate corresponding to the calcium that might be associated with chlorine; 0.0118 is the calcium sulphate that might be formed from all the SO_4 radicle present. The values 0.0246Na and 0.0145K represent the calcium sulphate corresponding to these two metals. The value for the parenthesis of this formula must not exceed $0.0118SO_4$ or 0.0283Ca in order that deposition of impossible amounts of scale shall not be indicated.

These two formulas permit calculation of the hardness of the scale which a water will form. The coefficient of scale hardness, h, equals Hs divided by Sc.

PREVENTION OF SCALE.

WATER SOFTENING.

The waters of Iowa are undesirably hard for steam boilers and for most industrial purposes. This is especially true of well waters. The condition is a permanent one and the inconvenience of using such waters in the natural state will increase as the industries of the state are developed. It would seem in the natural order of development that the softening of water for industrial purposes should become general, as the apparatus and processes are improved and as the advantages become better understood. Already good beginnings have been made. Several railroads are successfully operating softening plants within the state. Of these the Chicago & North Western Railway has made the widest application of the process, having twenty-two plants in Iowa with a total capacity of 5,500,000 gallons a day. Several ice, traction, lighting, heating and manufacturing concerns are operating on a large scale plants in which the principles of water softening are employed in a thorough-going way, aiming at the removal of all the scale-forming material possible. The plants operate in the cold and probably give as good results in point of efficiency and economy as are obtainable at the present time.

METHODS OF SOFTENING WATER.

In softening water the main purpose is to remove those substances which form scale—calcium, magnesium, aluminum, iron, silica, the carbonate radicles, and suspended matter. The hydrogen ions are removed when water is softened by the use of alkalies, thus rendering the water practically noncorrosive. These results should be accomplished with the addition of a minimum of foreign substances, which in small quantities should be harmless. The methods may be classified as follows:

Hot softening:
1. (*a*) Heating the water alone, usually in a feed-water heater.
   (*b*) Heating the water and adding chemicals.
2. Heating in the boiler, and using a boiler compound.
3. Heating in a separate plant with chemicals.

Cold softening:
4. Treating in a separate plant with chemicals, usually lime and soda ash.

HOT SOFTENING.

In feed-water heaters.—Purification of water by heating it is usually carried out in a feed-water heater, or preheater, in which the raw water is heated with exhaust steam and is fed to the boiler at about the boiling temperature. The boiling of water containing considerable quantities of calcium, magnesium and the bicarbonate radicle causes the precipitation of calcium carbonate and basic magnesium carbonate, which continues till either the basic or the acid radicle is exhausted. The hydroxides of iron and aluminum may be precipitated at the same time. The substances in the water may be present in such proportions that the whole of the incrusting solids are removed to the limit of solubility of the carbonates and hydroxides. In the feed-water heater, however, the water is usually not actively boiled, and any one portion of the water remains near the boiling point only a short time before it is run into the boiler. The result is that the precipitation is far from complete. In most waters the content of calcium and magnesium together is more than equivalent to the bicarbonate radicles. In many installations the aim is, therefore, to add the necessary amount of carbonates in the form of soda ash.

Forms of feed-water heaters are many, but they may all be classified under two general heads, as closed heaters and open heaters. Closed heaters are those heaters in which the steam is conducted through tubes placed in the water to be heated and purified or those in which the water passes through pipes surrounded by exhaust steam. Open heaters include those in which the water is sprayed into chambers or run in thin sheets over plates in immediate contact with the steam, and this style has the advantage of immediate contact of steam and water. In any form of feed water heater there should be a reservoir at the bottom, undisturbed by strong currents of either water or steam, where the precipitated matter may settle and from which the "sludge" may easily be drawn off. In some forms the hot purified water is carried from the upper part of this reservoir directly into the boiler and in others it is drawn from a compartment separated from the settling chamber by suitable filtering units.

Aside from their merits as economizers of fuel, feed-water heaters have the advantage of permitting the precipitation of the mineral matter where it can easily be removed—that is, before it reaches the boiler. Furthermore, the mineral matter is far less likely to form scale. For the most part it is deposited as a powdery mass which can easily be washed out. In the closed feed-water heater the temperature of the metal does not rise above about 100°C, and in the open heater metallic heating surfaces scarcely come into account.

Hot softening in boilers.—Competent engineers generally agree that the time to soften a water is before it enters the boiler, where the sludge can be most harmful and where it is the most difficult to remove. Softening in the boiler is probably to be regarded as a poor make-shift, justifiable only where the accessory softening apparatus can not be provided; nevertheless, the use of boiler compounds seems to be fairly general.

The number of boiler compounds on the market is large. Some which are intended to precipitate the mineral matter in the boiler, consist of soluble alkalies; others, intended to prevent the adherence of hard scale, may contain clay, sawdust, graphite, glycerin, and oils of various sorts; others are said to contain acids and acid salts, such as acid sodium sulphate.

If no better scheme than that of using chemicals in the boiler is available, this should at any rate be done with due regard to the requirements of the case in hand. It is obvious that any general commercial boiler compound can only by chance be suitable for any specific water. To get the best results the substance used, in most cases a mixture of the alkalies, should correspond in its composition and in the amount used to the particular requirements of the water to be treated. An accurate mineral analysis of the water should be made, and then a boiler compound should be made for that water. It should be used only in sufficient amount to cause complete precipitation of scale-forming substances. Sodium carbonate will probably serve the purpose best.

Hot softening away from the boiler.—There is no great difference between the chemistry of this process and feed-water heating save that the apparatus is a separate one and the water is stored and used as required. It is less economical, since the water is stored and allowed to cool. The precipitation and settling of the sludge are, however, facilitated by heat.

COLD SOFTENING.

Probably the most thorough-going and extensive application of the principles of water softening is to be found in the large plants for the softening of hard water at ordinary temperature. Though there are many forms of apparatus for this purpose now in use, their principles of operation are much the same. They are to a large extent automatic. The water to be softened is measured by some sort of automatic device, and the same may be said of the chemicals in solution or suspension. For example, in the apparatus designed by George M. Davidson for the Chicago & North Western Railway Company the water to be softened is measured in two tilting vessels holding about 100 gallons each. These are geared to pumps with cylinders of adjustable capacity which supply the chemicals in known quantities parallel to the volumes of water to be softened. The weight of the water also supplies power for the stirring in the precipitation tank. In other forms power is supplied by means of a water wheel, as in the Kinnicut apparatus. All forms have several separate vessels, including chemical tanks or boxes, a precipitation tank, usually two settling tanks, and a storage tank. To secure compactness some of these are reduced to compartments, as in the Kinnicut apparatus. The capacities of such plants vary with the requirements, some having as small capacity as 200 and others as large as 60,000 gallons per hour.

The softening of water in the cold is accomplished by precipitating the objectionable or scale-forming material in the form of hydroxides and normal and basic carbonates. It is necessary to add hydroxyl radicles to neutralize hydrogen so as to form the hydroxides of iron, aluminum, and magnesium and to convert the bicarbonate radicles and dissolved carbon dioxide into normal carbonate radicles in order to precipitate calcium. If the amount of normal carbonates is not sufficient to precipitate the calcium, then carbonate radicle must be added, usually in the form of soda ash. Sodium hydroxide might be used to supply the hydroxyl radicles, which would introduce comparatively harmless amounts of sodium, but lime is commonly preferred on account of its cheapness. The calcium introduced by the use of lime must in turn be removed as carbonate, for which extra soda ash may be required.

The following equations express at least approximately the reactions involved:

$$\overset{+}{H} + \overset{-}{HO} = H_2O \qquad \overset{-}{HCO_3} + \overset{-}{OH} = H_2O + \overset{=}{CO_3}$$

$$\overset{+++}{Al} + 3\,\overset{-}{OH} = Al\,(OH)_3 \qquad CO_2 + 2\,\overset{-}{OH} = H_2O + \overset{=}{CO_3}$$

$$\overset{++}{Fe} + 2\,\overset{-}{OH} = Fe\,(OH)_2 \qquad \overset{++}{Ca} + \overset{=}{CO_3} = CaCO_3$$

$$\overset{++}{Mg} + 2\,\overset{-}{OH} = Mg\,(OH)_2$$

Leaving out of account the small amount of silica, the sulphate radicle is the only substance, of those commonly found in scale, that remains in the water at the end of this process. However, this radicle is now associated for the most part with sodium. Sodium sulphate is very soluble in water and is not likely to cause trouble until it becomes concentrated enough to aid materially in causing the water to foam.

Stabler[1] has given, perhaps in the most scientific and convenient form, formulas for the calculation of the weights of soda ash and of lime which must be added to soften in the cold a water of known mineral content. The first gives the lime required and the second the soda ash which the same water will require, if it requires any, after the lime has been added:

$$\text{Lime required} = 0.00931Fe + 0.0288Al + 0.0213Mg + 0.258H + 0.00246HCO_3 + 0.0118CO_2.$$

$$\text{Soda ash required} = 0.0167Fe + 0.0515Al + 0.0232Ca + 0.0382Mg + 0.462H - 0.0155CO_2 - 0.00763HCO_3.$$

The two equations give, respectively, the amounts of lime 90 per cent pure and of soda ash 95 per cent pure required to precipitate in the cold the scale-forming ingredients and to neutralize the corrosive ingredients. The manner of deducing the coefficients is explained in Mr. Stabler's report. The symbols in the equations represent the amounts in parts per million of the constituents of the water. If the second equation has a negative value or is equal to zero, no soda ash is required.

It will be noted that these formulas take no account of the

[1]Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 170.

hypothetical salts that may exist in the water solution, and rightly so, for the present theory is that in such dilute solutions there is almost complete electrolytic dissociation. In practice the formulas may be simplified without leading to large errors and in many waters the errors would not be perceptible. In Iowa waters iron and aluminum rarely exceed one or two parts per million, the normal carbonate radicle is rarely present, and acid hydrogen is also exceedingly small in amount. In the majority of computations, therefore, only calcium, magnesium, the bicarbonate radicle, and free carbonic acid need be taken into account. It is probable, moreover, that where only one to two parts per million of iron and aluminum are present they could not be removed even in part by softening, because the amounts of their hydroxides possible would not exceed the solubility limit of those hydroxides.

LIMITS IN REMOVING INCRUSTING MATTER.

It is not possible to remove all of the incrusting matter from water by precipitation, as none of the compounds that are formed are wholly insoluble. If it is assumed that calcium carbonate and the hydroxides of magnesium, iron, and aluminum would be dissolved in the purified water to the same extent as in pure water, there would be about forty parts per million of the four incrustants remaining in solution. The solubility of aluminum hydroxide is here rated as about the average of the other three compounds. Forty parts per million may be taken as about the limit of efficiency in water softening ideally carried out. In practice there is not always time for thorough mixing, nor for the reactions to complete themselves, nor for thorough settling. It can scarcely be claimed that analyses are perfect and that the chemicals are accurately adjusted to the work to be done. In view of these difficulties it is not surprising to find that in practice the amount of incrusting matter remaining ranges from 50 to 100 parts per million. The average is about 70 parts, an amount of scale-forming material so small as to be regarded as comparatively harmless. In practice the residual incrusting matter seems to be within wide limits, largely independent of the amount originally present.

COST OF SOFTENING WATER.

So far as relates to the cost of the plants themselves, little information can be given, as they differ widely in form, materials and capacities. The cost of operating expenses and chemicals ranges from one cent to ten cents per 1,000 gallons. The average is about three cents in Iowa plants, so far as information has been obtained. The cost for chemicals is very small for waters in which the calcium and magnesium do not exceed in chemical equivalence the carbonate radicles present, as for these waters only lime is required. Where the contrary is true the carbonates must be supplemented by the addition of the more expensive soda ash. In a general way, however, the cost of chemicals runs parallel to the unsuitableness of the water for boiler use in its natural state.

Considerable information has been collected relating to the profitableness of softening plants, and it is uniformly to the effect that they far more than repay their cost. The Chicago & North Western Railway Company, which has taken up water softening on a more extensive scale than any other institution in the state, reports that the results are very gratifying, the cost being more than repaid by the economy of fuel, the increased life of boilers, the efficiency of the engines while working, and the great decrease in their periods of idleness in the repair shops.

SUMMARY.

The subject of water softening has been treated fully because it is believed that its use should be greatly extended in the state and should become general where water is used in considerable quantities for industrial purposes. It has already been proved practicable and profitable when carried out on a large scale. Great improvements in the process have been made in the last few years, and still further improvement in the way of cheapness and simplicity is likely. It does not seem probable that a people so thoroughly progressive in other respects should be satisfied with what nature gave them in the way of water for industrial purposes, any more than they have been content to depend for their town supplies on private wells or on a public system with polluted water unsuitable for domestic purposes.

Among the cities and towns of Iowa sharp rivalry and keen competition exists in securing industrial establishments which may contribute to their growth and wealth. Water systems have been installed in many towns sooner than they would otherwise have been, in order to obtain suitable protection from fire and more favorable insurance rates, and especially in the larger towns, to benefit the manufacturing interests and to induce other concerns to locate in them. In some towns private companies have been organized to put in supplementary systems of water more suitable than the city water for boiler and other industrial uses. Several years ago public-spirited citizens of Grinnell bought suitably located land, built a dam for an artificial lake, and put in the necessary conducting mains, pumping machinery, and storage, at a cost of about $40,000, to make the water of this lake available for industrial uses.

Any establishment using large volumes of water can well afford to install its own softening plant, and in some places the manufacturing interests may well combine to erect and operate a softening plant to treat for their purposes water drawn from the city system. It undoubtedly could be done for a small fraction of the outlay necessary to put in a whole extra water system, and probably it would secure a far better water.

CORROSION OF BOILERS.

NATURE AND LOCATION.

Corrosion of boilers may be general over considerable surfaces; it may take the form of grooving in the direction in which the iron was rolled or drawn, or it may be localized at certain points producing depressions, known as "pits." Sometimes the pits may be concealed by prominences composed of adherent rust formed at the expense of the iron. Corrosion is likely to take place more rapidly on the bottom plate of the boiler; at the water line, especially if the boiler is used intermittently; around bolt heads and stays; and near the water intake.

CAUSES OF CORROSION.

The corrosive action may be assumed to take place at ordinary temperature, and the theory may be applied to the ordinary rusting of iron in the presence of air and natural water. At boiler temperature the corrosive action is in many respects the same, though it may be much accelerated by heat. Some additional phases, however, must be considered, the most important being the apparent direct decomposition of the water by the heated iron, accompanied by its oxidation, and the supposed hydrolysis of magnesium chloride setting free hydrochloric acid. Ost[1] has furnished much information on these two subjects.

In many textbooks and papers dealing with the corrosive action of water it is stated that magnesium chloride undergoes hydrolysis when its solution is boiled, setting free hydrochloric acid, and that, therefore, water containing this salt can not be used in boilers. This statement has apparently been copied from Wagner.[2] It is true that when the hexahydrate of magnesium is heated, it undergoes some hydrolysis and forms some hydrochloric acid, but that any such action takes place on heating a dilute solution of magnesium chloride, such as would occur in boilers, seems doubtful. Ost studied the action of salts and especially of magnesium chloride on iron under the ordinary conditions of temperature and pressure in steam boilers. He used boilers of about 2½ liters capacity, made of iron, copper, and copper lined with tin. He first distilled dilute solutions of magnesium chloride to a concentration of 20 per cent, and found the distilled water free from hydrochloric acid, though the copper and the tin vessels were attacked. He then repeated his experiments with a boiler of Krupp-Siemans-Martin steel, at a pressure of 10 atmospheres, corresponding to a temperature of 183° C. After every experiment, no matter whether pure water or salt solutions were used, the surface of the boiler was covered with a dark layer of ferrous oxide. As air was excluded Ost could assign the formation of oxide only to the decomposition of water, which, as special experiments showed, took place to some extent even at 100° C.

[1]Chem.-Zeitung, vol. 26, pp. 819, 845.
[2]Dingler's Polytech. Jour., vol. 218, p. 70.

In a series of experiments magnesium chloride, potassium chloride, sodium sulphate, potassium sulphate, calcium chloride, and magnesium sulphate, in five per cent solution, were tried. The solutions produced approximately the same amount of ferrous oxide, but iron went into solution only when magnesium sulphate or magnesium chloride was used. The solution of iron was not proportional to the decomposition of water and the oxidation of the iron. The last was strongest when calcium chloride, potassium chloride, potassium sulphate, and sodium sulphate were used. Magnesium chloride, therefore, can not dissolve iron through hydrochloric acid formed by its hydrolysis. The fact that iron goes into solution when magnesium salts are used is due, according to Ost, to the reactions

$$MgCl_2 + Fe(OH)_2 \rightleftharpoons FeCl_2 + Mg(OH)_2$$
$$MgSO_4 + Fe(OH)_2 \rightleftharpoons FeSO_4 + Mg(OH)_2$$

These reactions are reversible and with equivalents present should run preponderatingly from right to left. The reversal is due to the mass of magnesium salts.

From these experiments it seems evident that magnesium chloride has not the high corrosive action on boilers usually ascribed to it. It is not to be classed with salts of copper, iron, and aluminum, which undergo hydrolysis even at ordinary temperature. The facts seem to be that neither the salts of magnesium nor those of calcium, potassium, or sodium, when the negative radicle is that of a strong acid, have essentially more corrosive action on iron than water itself at the same temperature with air excluded.

Ost found that under a pressure of 10 atmospheres a magnesium salt loses its power to carry iron into solution when one-fourth of its equivalent of calcium carbonate is present. The explanation is that the magnesium salt and the calcium carbonate react, forming magnesium basic carbonate and hydroxide, which serve to drive the above reaction from right to left. In this and in other ways calcium carbonate may check corrosion. It is not entirely insoluble in water, and the dissolved portion may be assumed to be dissociated. It may react with any strong acid present, forming carbonic acid which will be decomposed and thrown out of the chemical system at higher temperatures, thus,

$$\overset{++}{Ca}, \overset{=}{CO_3} + 2\,\overset{+}{H}, \overset{==}{SO_4} = \overset{++}{Ca}, \overset{=}{SO_4} + H_2O + CO_2$$

INTERPRETATION OF ANALYSES WITH REFERENCE TO CORROSION.

In the corrosion of iron the metal takes the place of some other positive radicle, as for example, hydrogen which may escape, or copper which may be precipitated. There seems little doubt that in practice the hydrogen radicle is almost the only agent of corrosion. As already indicated, ionic hydrogen may be present in the cold water, and its amount may be increased by increased hydrolysis of copper, iron, and aluminum at high temperatures. Though we are hardly justified in adding magnesium, it may, as Ost has indicated, aid in the solution of iron already oxidized.

Certain substances, on the other hand, restrain or prevent corrosion—that is, they tend to neutralize the hydrogen radicles. The soluble carbonates have been mentioned. The water is corrosive or noncorrosive according to the preponderance of the corrosive agents or of the restrainers. It is very desirable to know from the analysis of a water whether it is likely to be corrosive or not, but it is evident from contemplation of the large number of substances that ordinary water may contain that the problem is somewhat complex. Stabler[1] has proposed a formula by which it may be inferred whether a water is likely to be corrosive or not. C, the coefficient of corrosion, is computed thus:

$$C = 1.008\ (rH + rAl + rFe + rMg - rCO_3 - rHCO_3)$$

Here r is the reacting weight of the respective radicles with which it is associated and the reciprocal of the equivalents of those radicles; H, Al, Fe, etc., are the weights of these substances in parts per million as found by analysis. If r is multiplied by the weight in milligrams of the element and the product multiplied by 1.008 the result will be the weight of acid hydrogen chemically equivalent to the radicle. Supplying the value of r and multiplying through by 1.008, we have the equation:

$$C = H + 0.1116\ Al + 0.036\ Fe + 0.0828\ Mg - 0.0336CO_3 - 0.165HCO_3$$

[1]Water-Supply Paper U. S. Geol. Survey No. 274, 1911, p. 175.

That is, the weight of ionic hydrogen that may appear on heating the water is equal to the weight of hydrogen radicle found by analysis (the acidity expressed in terms of hydrogen), plus the hydrogen equivalents of iron, aluminum, and magnesium, minus the hydrogen equivalents of the carbonate and bicarbonate radicles. In interpreting the value of C due regard must be paid to the fact that calcium carbonate may be precipitated on boiling, since this carries out of the system the carbonate radicle with which hydrogen may unite to form water and carbonic acid. Granting that all possible calcium carbonate will be precipitated, and that the neutralizing action of this solid is nothing, the effect of the carbonate radicle to counteract corrosion will be reduced by 1.008. rCa, or 0.0503 Ca. With this latter value in view, three cases may be distinguished:

1. If C is positive, corrosion will certainly occur.
2. If C+0.0503Ca is negative, no corrosion due to mineral matter will occur.
3. If C is negative and C+0.0503Ca positive, corrosion may or may not occur.

As the coefficient of corrosion is equivalent to the concentration of the hydrogen ions, corrosion is in general proportional to the positive value that can be assigned to C. There is reason to believe, however, that corrosion is facilitated by certain other conditions. The reason that pure zinc will not readily dissolve in pure acid seems to be that its surface quickly becomes covered with a film of hydrogen which prevents further action. If, however, the zinc is placed in contact with some metal of lower solution pressure, such as lead or copper, or with some indifferent but conducting substance, such as graphite, an electric battery or couple is formed. The hydrogen then appears on the second metal or on the graphite, and the action of the acid on the zinc is greatly accelerated. This principle has wide application in accounting for the corrosion of iron. Rust once formed on a boiler plate or tube acts toward the uncorroded iron in the same way as the copper toward the zinc in the instance just described—that is, the mass of rust becomes the cathode plate and the iron the anode of an electric couple and the rusting of the iron is greatly increased. Once the action is started it is likely to continue and spread at that place, producing a nodule of rust under which is a pit in the metal. A familiar illustration may be given. Every one has observed that a polished tool such as a knife blade, a saw, or a chisel may long remain bright and free from rust, but that once it has been attacked by rust, the action will continue in spite of all ordinary attempts to prevent it. The same electric action may take place around the bolt heads when the bolts and the plates are not made of the same quality of iron. Even the same piece of iron may not be homogeneous in its composition, and therefore, one part may be anode and a neighboring one may be cathode. It is probable that the grooving of iron by rusting may be accounted for in this way.

CHAPTER VII.

MINERAL WATERS.

BY W. S. HENDRIXSON.

DEFINITION

All natural waters, whether from streams, lakes, or wells, are mineral in the sense that they contain in greater or smaller amounts certain chemical substances occurring on or near the surface of the earth. Popularly, however, the term "mineral waters" is used to designate waters that contain unusual substances in solution or common substances in unusual amounts. The term is often applied to waters containing some constituent observable directly by the senses, such as sufficient iron to stain rocks near springs or enough hydrogen sulphide to be detectable by the odor. Many waters contain enough of certain radicles, such as chloride or sulphate, to possess a decided taste, and these are classed as "mineral waters." Analyses of many commercial mineral waters show that they contain no appreciable amounts of substances not ordinarily found in most natural waters, or that they contain traces of substances not usually sought for in the analysis of water, but in amounts too small to have any medicinal value. The character of commercial mineral waters is well shown by the analyses of 53 of of the most prominent of such waters made by the Department of Agriculture.[1]

MEDICINAL VALUE

Probably the best drinking water for most persons is organically pure water containing in small amounts only the usual

[1]Haywood, J. K., Mineral waters of the United States: Bull. No. 91, Bur. Chemistry, U. S. Dept. Agr., 1905.

inorganic constituents found in nearly all natural waters, for to such water the human system is apparently best adjusted. The amounts of such matter may apparently be greatly varied without causing any observable bad effects. No very definite evidence that waters containing as much as 1,000 parts per million of the common ingredients are temporarily or permanently injurious is obtainable. When the solids are much greater than this amount, the waters are objectionable to many persons because of their taste, and they may prove laxative, at least till persons become accustomed to them. This is, of course, more likely to occur if the sulphates are large in amount.

The medicinal effect of mineral waters is open to investigation and discussion, for no comprehensive and scientific investigation on this subject, dealing with large numbers of patients and a variety of well-characterized waters, has been carried out. It does not inspire confidence in the healing powers of mineral waters to find that the same water is recommended to cure a great variety of unrelated diseases, that very different waters are advertised to cure the same disease, and that, perhaps, the majority of "mineral waters" do not differ materially in their mineral content from widely distributed normal waters that are used by thousands of persons without a thought of their possessing any special medicinal value. It is by no means conclusive evidence of the therapeutic value of mineral waters that many persons who visit mineral-spring resorts and sanitariums are benefited. The very fact that persons suffering from a large variety of diseases are helped by one and the same water would seem to indicate that the mineral content of the water has little to do with it. Persons who visit such institutions are subjected to conditions different from those surrounding their own homes; they are temporarily relieved from burdensome cares and are more or less firmly convinced that they will be benefited or cured; they take normal exercise, stay out of doors, and drink plenty of water, thus cleansing their stomachs and regulating their body functions. Such conditions are powerful factors in curing disease.

Medicinal value may, however, be ascribed to mineral waters of certain kinds. Considerable amounts of lithium may assist in eliminating uric acid and calculi, and the iron of the water may possibly prevent undue loss of organic iron in anemia. Alkaline waters may correct too great acidity in the digestive tract, and magnesium or sodium sulphates may prevent constipation.

EXTENT OF MINERALIZATION

The main purpose of this study has been to determine the suitability of Iowa waters for industrial and not for physiologic purposes, and no attempt has been made to determine lithium and some other substances occurring rarely and in very small amounts. Doubtless lithium occurs in quantities detectable by the spectroscope in some Iowa waters, but probably not in sufficient amounts to make the waters physiologically beneficial to those using them. Iowa waters, like commercial mineral waters, should be judged by their content of the substances occurring in measurable amount in them. If they are rated in this way, there appears no evident reason why many Iowa waters should not be considered equal to well-known mineral waters. Many waters on sale are so highly mineralized that they are not suitable for general industrial or domestic use, and their characteristics are not unlike many in Iowa that well drillers avoid and case out. To make this fact plain, comparisons of some well-known commercial mineral waters with typical Iowa waters are made. Few well waters in Iowa are so lightly mineralized as those given in the following table:

Comparison of light mineral waters with two Iowa waters and with Lake Michigan water.

[Parts per million]

Locality and Name of Water	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Lithium	Total *a*	Analyst
Manchester, Iowa:														
Spring, United States fish hatchery.	10	----	0	1	50	20	5	1	207	11	4	----	309	W. S. Hendrixson.
Atlantic, Iowa:														
City well	22	----	1.4	2.6	43	13		10	144	30	10	----	276	Do.
Lake Michigan	5	----	----	0.2	32	11		3	144	7	2	----	204	Geo. M. Davidson.
Amelia Courthouse, Va.:														
Otterburn Lithia	43	1.5	----	----	20	6.7	7.8	1.9	112	2.8	4.6	0.03	*b* 201	(*f*).
Danville, Va.:														
Sublett Lithia	31	1.0	----	----	37	12	15	2.6	166	5.9	10	T.	*c* 288	(*f*).
Fulton, N. Y.:														
Great Bear	9.7	.3	----	----	31	10	10	1.7	118	8.8	22	T.	*d* 300	(*f*).
Crumpler, N. C.:														
Thompson's Bromine	63	1.0	----	----	7	2.2	22	2.7	81	6.1	4.0	T.	*e* 193	(*f*).

*a*Sum of constituents without subtracting one-half the bicarbonate radicle.
*b*Nitrite radicle (NO_2), .003 part per million; ammonium radicle (NH_4), .069 part.
*c*Nitrate radicle (NO_3), 7.08 parts; ammonium radicle (NH_4), .005 part.
*d*Nitrate radicle (NO_3), 88.6 parts; ammonium radicle (NH_4), .01 part.
*e*Nitrate radicle (NO_3), 3.54 parts; ammonium radicle (NH_4), .04 part.
*f*Haywood, J. K., op. cit., pp. 42, 51, 61, 73.

The well water from Atlantic, Iowa, is chosen on account of its small content of mineral matter for a well water. That from Manchester, Iowa, may be considered typical of the best waters of the large springs in Iowa. The Lake Michigan water is included because the analysis represents the average quality of water drawn from widely different sources and because it is not considered an exceptional water possessing special medicinal properties.

The next table compares three mineral waters of rather low total solids with one of the best deep-well waters of Iowa. This water represents in a general way the well waters of the northeastern part of the state, which are excellent drinking waters and which, according to the analyses, are as good as the mineral waters. In the one of these waters containing a weighable amount of lithium the amount is so small that one would have to drink about 75 gallons of the water to obtain a normal medicinal dose of lithium.

Comparison of certain mineral waters with a well water at Dubuque, Iowa.

(Parts per million.)

Locality and Name of Water	Analyst	Silica (SiO_2)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Lithium	Total *a*
Dubuque, Iowa:													
City Gas Co.'s well	W. S. Hendrixson	5	1	1	56	33	4	8	310	12	10	----	435
Staunton, Va.:													
Golindo Lithia	(*b*	12	.3		74	29	4.7	3.4	333	33	3.4	0.1	*c* 496
Pleasant Valley, Va.:													
Osceola	(*b*)	20	.14		53	29	7.0	2.0	315	1.6	3.4	N.	*d* 435
Harrisburg, Pa.:													
Massenetta	(*b*)	12	.3		63	28	3.9	3.1	342	2.8	1.8	T.	*e* 459

*a*Sum of the constituents without subtracting one-half the bicarbonate radicle.
*b*Haywood, J. K., op. cit., pp. 53, 52, 34.
*c*Nitrate radicle (NO_3), 3.5 parts per million.
*d*Nitrate radicle (NO_3), 4.0 parts; ammonium radicle (NH_4), .04 part.
*e*Nitrate radicle (NO_3), 2.2 parts; ammonium radicle (NH_4), .185 part.

In the third table four mineral waters are compared with the objectionable well water from Farmington, Iowa. All five are typical hard waters of the calcium sulphate type, a type which should be rejected as a source of municipal supply. A similar parallelism might be drawn between other commercial waters and other more strongly mineralized Iowa waters, but from this table it may be inferred that Iowa is well supplied with mineral waters, according to popular acceptance of that term. The northeastern part of the state has an abundance of organically pure and lightly mineralized water which might legitimately be sold as high-grade table waters.

Comparison of heavily mineralized commercial waters with the city well water. Farmington, Iowa.

(Parts per million.)

Locality and Name of Water	Analyst	Silica (SiO_2)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Lithium	Total
Farmington, Iowa:													
Deep well	W. S. Hendrixson	13	---	2	340	112	442	15	248	1,658	230	----	3,060
Geneva, N. Y.:													
Geneva Lithia	(*b*)	14	0.7	---	522	116	131	4.0	245	1,520	204	0.1	*c* 2,757
Elkwood, Va.:													
Berry Hill	(*b*)	28	1.5	---	525	59	164	3.4	151	1,686	26	T.	*d* 2,644
Bedford, Pa.:													
Bedford	(*b*)	37	2.1	---	570	139	13	4.9	192	1,728	10	T.	*e* 2,696
Tate Springs, Tenn.:													
Tate Epsom	(*b*)	22	2.9	---	475	121	25	8.2	260	1,460	9.2	.1	*f* 2,383

*a*Sum of the constituents without subtracting one-half the bicarbonate radicle.
*b*Haywood, J. K., op. cit., pp. 41, 59, 36, 37.
*c*Nitrate radicle (NO_3), 0.44 part per million; ammonium radicle (NH_4) 0.016 part.
*d*Nitrite radicle (NO_2) 0.009 part; ammonium radicle (NH_4) 0.53 part.
*e*Nitrate radicle (NO_3) 0.21 part; ammonium radicle (NH_4) 0.015 part.
*f*Nitrate radicle (NO_3) 0.21 part; ammonium radicle (NH_4) 0.01 part.

A few Iowa waters are advertised as having curative properties. The most noted is that from wells about 300 feet in depth in and near Colfax. In the lower parts of the city they are flowing wells and all yield the same quality of water. Several hotels and sanitariums owe their popularity in no small measure to the reputation of the Colfax water, which is sold in large quantities. Essentially the same quality of water is found in several wells in the same county and in other parts of the state. Those in Jasper and Polk counties probably draw their water from the same source, the Carboniferous, and probably from the Pennsylvanian or the underlying Saint Louis limestone (Mississippian). At the beginning and at the end of the following table are analyses of two representative Colfax waters and between them are analyses of several waters from the same locality and from other parts of Iowa. All are highly mineralized but contain only moderate amounts of calcium in comparison with the large amounts of sodium and sulphates.

Comparison of water from Colfax, Iowa, with other hard Iowa waters.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids [a]	Analyst
Colfax: Sanitarium	371	Carboniferous	10	0.2	1.5	211	99	420		260	1,505	29	2,406	H. S. Spaulding.
Des Moines: City library well	375	Pennsylvanian	14	1	3	237	53	559	7	312	1,569	107	2,706	W. S. Hendrixson
Runnells: Robert Blee	228	Des Moines	12	0.5	1	108	39	715		414	1,520	48	2,645	Do.
Mount Pleasant: Hospital for Insane	1,267	Saint Peter	10	8	1	198	71	400	14	280	1,214	157	2,213	Do.
Fontanelle: J. H. Hulbert	269	Cretaceous	20	3	1	231	69	412		264	1,822	84	2,274	Do.
Knoxville: Hospital for Inebriates.	326	Pennsylvanian	10	0.4	3	303	52	436		262	1,600	18	2,553	Do.
Kellerton: Robert Hall	375	Carboniferous	55	5	9	249	87	521		439	1,477	46	2,673	
Colfax: Mills Hotel	350	Do.	11	0.7	1	235	97	463		260	1,495	27	2,460	H. S. Spaulding

[a] Sum of constituents minus one-half the bicarbonate radicle.

Water from the well of S. C. Johnston at Flagler is sold in considerable quantities. It is very heavily mineralized, the solids being nearly 9,000 parts per million, including very high calcium, sodium, and sulphates. It differs little from the water of the city well at Pella, which is used only for fire protection and for sprinkling the streets and is probably derived from the same geologic formation. Thompson Craig's well at Knoxville also yields about the same kind of water. Water is also sold from the Red Mineral Spring at Eddyville. It is recommended as an antiseptic water for both internal and external use. Small samples received at this laboratory seem to justify the statement that it is antiseptic, as they contain considerable amounts of free sulphuric acid, probably due to the oxidation and hydrolysis of ferrous sulphate. The amount of iron in the water is very large. From the character of the water and descriptions of the spring it may be concluded that the spring consists of a small flow from a layer of disintegrating shale containing iron pyrite. The well of Mrs. Cora A. Huber at Tama supplies a very heavily mineralized water, which is sold. It contains more than 5,500 parts of solids. It is very much the same as the Colfax water, except that the concentration of the constituents is nearly doubled. Water is is sold from some other wells and springs in the state, but so far as is known the amounts are comparatively insignificant.

TYPES OF MINERAL WATERS

SCHEME OF CLASSIFICATION.

The radicles determined in the analytical work of this investigation have already been given (p. 159). It seems desirable to make some general statements concerning the variations in the amounts of these radicles, and to indicate a scheme of classification by which the waters may be arranged in groups so as to bring more clearly before the mind the similarities and differences in their quality.

The ground waters of Iowa can not be separated into distinct classes with the representatives of one class clearly differentiated from those of any other, for they grade into each other by almost insensible differences. Much overlapping of groups occurs in any system of classification, and the relationships of the waters to ideal types can be indicated in only a general way. No attempt is made to classify all the waters of the state, but only to select a few good representatives of each class as illustrations of the system and method.

For classification purposes the following scheme of J. K. Haywood and R. H. Smith, chemists of the United States Department of Agriculture,[1] is used.

Thermal or non-thermal.	Sodic. Lithic. Potassic. Calcic. Magnesic. Ferruginous. Aluminic.	Carbonated or bicarbonated. Borated. Silicated.	Alkaline.	Arsenic. Bromic. Iodic. Siliceous Boric. Lithic. Ferruginous, etc.	Nongaseous. Carbondioxated. Sulphureted. Carbureted. Oxygenated.
		Sulphated. Muriated. Nitrated.	Alkaline-saline		
		Sulphuted. Muriated. Nitrated.	Saline.		
		Sulphated. Muriated.	Acid.		

For the classification of Iowa waters, as analyzed, only a few of the classes in this table, which is elaborate enough to include almost any mineral water, are required, but it is nevertheless

[1]Haywood, J. K., op. cit., p. 11.

given entire for the sake of completeness. In the analyses no attempt was made to determine unusual substances that might occur in small amounts, such as bromine, iodine, arsenic, and the common gases of the air, since these substances in the quantities in which they might occur would have little or no relation to the primary practical objects of this study. It should be stated, however, that free carbon dioxide dissolved in water was determined. It was found present in all but two or three samples, in amounts rarely exceeding 25 parts per million. For this reason all waters with the exceptions noted have been regarded as containing their carbonates in the acid form, or, in other words, as HCO_3. Hydrogen sulphide, H_2S, has often been noted in Iowa well waters, and it has been determined in a few waters. It was rarely apparent when the waters reached the laboratory, and since the small amount that might persist after shipment could give little information as to the amount present in the water as it came from the well, this gas was not determined.

In the following arrangement of examples the classification is governed by the prominence or preponderance of certain radicles. Certain constituents are common to nearly all ground waters within the state. All such natural waters contain some chlorine, some bicarbonates, rarely normal carbonates, and nearly all contain nominal amounts of sulphates. All contain at least a few parts per million of calcium and magnesium. Such constituents are not taken into account in the nomenclature unless they occur in sufficient amounts to give the waters the distinctive characteristics which they might impart. For example, water is not classified as sulphated unless it contains the sulphate radical in large amount; that is, 250 parts per million or more of SO_4. In the same way a quantity of chlorine less than 100 parts is not regarded as sufficient to justify calling a water "muriated."

SODIC MURIATED ALKALINE-SALINE WATERS.

Water in which sodium and chlorine predominate and which are alkaline to methyl orange belong to the class of sodic muriated alkaline-saline waters. The other common constituents may be present in small or moderate amounts.

None of the wells in Iowa so far as investigated yields strictly salt water or brine; salt is the largest constituent of the mineral matter in only a few waters. Nevertheless considerable amounts of chlorine, exceeding 100 parts per million, are of very frequent occurrence in Iowa ground waters. In several wells the chlorine reaches 500 parts or more; in the 1,006-foot well at McGregor and in the deep wells near Knoxville it reaches nearly 1,000 parts, and in the well at Bedford at a depth of 1,300 feet it reached 2,546 parts.

Salt-holding waters are generally distributed throughout the state, but such waters are especially common in certain localities. From the northeastern corner of the state southward along Mississippi river chlorine tends to increase. The deep wells of Allamakee county contain about 70 parts of chlorine. It rises to 246 parts in the 520-foot well at McGregor, in Clayton county, and to 968 parts in the 1,006-foot well at the same place, an amount exceeded only in the well at Bedford and the Craig well at Knoxville. At Dubuque the chlorine is scarcely more than a trace, but at Clinton it rises again to about 50 parts in the deeper wells. It increases southward from Clinton, being about 300 parts at Davenport and Burlington and about 600 parts at Keokuk and Fort Madison. Chlorine is present in amounts ranging from 100 to 2,500 parts in all deep wells tested in the southern part of the state. It reaches nearly 1,000 parts in the wells at Flagler, Pella, and Knoxville (Craig well), all in Marion county, and 2,546 parts at Bedford. The deep wells near Missouri river usually contain notable amounts of chlorine, but the quantities are smaller as a rule than those in the well waters along the eastern border of the state.

The wells in the central part of the state north of Des Moines do not contain excessive amounts of chlorine and rarely more than 100 parts. More than 100 parts are found in the deep wells at Fort Dodge, Boone, Ames, and Des Moines, and all of these penetrate the Jordan or lower formations.

The only essentially salt waters are those of the 1,006-foot well at McGregor and the Bedford well at 1,300 feet.

Analyses of sodic muriated alkaline-saline waters in Iowa.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids *a*
McGregor: City --------	1,006	Dresbach or underlying Cambrian sandstones ------	6	6	----	160	20	706	509	465	968	2,585
Bedford: Water Co.--	1,300		10	----	2	77	34	1,768	312	235	2,545	4,827

a Sum of the constituents minus one-half the bicarbonate radicle.

SODIC MURIATED-SULPHATED ALKALINE-SALINE WATERS.

Waters in which sodium, chlorine, and the sulphate radicle predominate are not common in Iowa. As a rule waters that contain much sulphates also contain much calcium and magnesium. Those given in the next table, as will be readily seen, contain little calcium and magnesium and are to be rated as soft waters. The first and second contain bicarbonates in excess of calcium and magnesium and would commonly be said to contain sodium carbonate. Such waters from deep wells are rare in this state.

Analyses of sodic muriated-sulphated alkaline-saline waters in Iowa.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids *a*
Glenwood: Institution for Feeble-minded	1,910	Silurian -	131	16	----	----	37	14	647	486	754	185	2,027
Logan: City -------------------------	821	-----------	10	----	0.3	2	35	15	461	411	728	121	1,578
Ames: State College ----------------	2,215	Jordan	3	----	----	4	35	15	391	204	516	204	1,270

a Sum of the constituents minus one-half of the bicarbonate radicle.

SODIC-CALCIC MURIATED-SULPHATED ALKALINE-SALINE WATERS.

Sodic-calcic muriated-sulphated alkaline-saline waters are much more common than members of either of the preceding classes. This class includes many of the most highly mineralized waters of the state, in which the most abundant constituents are sodium, calcium, chlorine, and the sulphate radicle. None of those enumerated can be regarded as fit for domestic or any other use except street sprinkling and putting out fires. In classification of Iowa waters there is no need of mentioning magnesium, as that radicle bears a regular relation to calcium; the Iowa water usually contains about one-quarter to one-half as much magnesium as calcium, and magnesium never has been found to exceed calcium.

Analyses of sodic-calcic muriated-sulphated alkaline-saline waters in Iowa.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids *a*
Bedford: Development Co.	2,002	Silurian	18	----	1	1	486	116	1,161		300	1,920	1,420	5,273
Burlington: Murray Iron Works	1,000	Saint Peter	11	----	1	1	342	115	514	11	232	1,860	235	3,206
Sanitary Milk Co.	484	Silurian	13	----	5	1	389	131	707	19	268	2,414	276	4,089
Centerville: City, No. 1	1,540	Silurian	10	3	----	----	263	90	755		90	1,961	339	3,465
Flagler: S. C. Johnson	752	Kinderhook	22	----	.4	3	486	167	2,236		306	4,839	925	8,831
Keokuk: Y. M. C. A.	769	Silurian ?	12	----	----	1	198	81	894	15	292	1,610	632	3,589
Knoxville: T. Craig	346	Des Moines	36	----	3	1	207	114	2,589		330	4,728	980	8,823
Ottumwa: Mineral Spring Co.	314	Mississippian	125	----	24	----	345	152	1,464		1,297	2,807	533	6,098
Pella: City	1,803	Saint Peter	10	----	4	3	488	148	2,107		280	4,678	775	8,353

a Sum of the constituents minus one-half of the bicarbonate radicle.

SODIC-CALCIC SULPHATED ALKALINE-SALINE WATERS.

The waters classed as sodic-calcic sulphated alkaline-saline are those of the common heavily mineralized type, containing the normal amount of bicarbonates found in nearly all Iowa waters, high percentages of calcium, sodium, and sulphates, and only small amounts of chlorine, usually less than 100 parts per million. Such waters are less objectionable for industrial purposes than plain calcic sulphated waters containing the same amount of total solids. In fact they are equivalent to calcic sulphated waters softened with sodium carbonate to the extent to which sodium replaces calcium. The sodium in them, if low, is comparatively harmless in industrial operations, since it does not consume soap or cause scale; but if the amount of it exceeds 200 parts per million it causes foaming in boilers.

Very many waters of Iowa belong to this class. The following table contains 15 good examples and they could be multiplied almost indefinitely. The more heavily mineralized waters have been selected in order to make the quantity and relative preponderance of the sodium, calcium, and sulphate radicles clear at a glance. Representatives of this class are all the deep wells at Grinnell and the numerous farm wells 250 to 450 feet deep near that city, which apparently get most of their water from the layer of clay and gravel just above the limestone at about 200 feet. Most of the wells in Webster, Tama, Benton, and Polk counties belong to this class.

Analyses of sodic-calcic sulphated alkaline-saline waters in Iowa.
(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids [a]
Amana:														
Amana Society ----	1,640	-------------	5	6.4	----	----	104	42	181		320	517	18	1,033
Cantril:														
C. J. Manning------	900	Maquoketa -	16	----	3	1	270	89	299		228	1,306	19	2,117
Cherokee:														
State Hospital ----	1,126	Saint Peter--	13	----	8	1	220	53	258		306	651	20	1,387
Colfax:														
Mills Hotel --------	350	Saint Louis-	11	----	.7	1	235	97	463		260	1,495	27	2,460
Dunlap:														
City ---------------	1,535	Saint Peter--	8	----	0	0	176	72	146	27	272	776	33	1,374
Grinnell:														
City (3) -----------	2,020	New Richmond.	13	----	2	.3	131	48	183		324	574	34	1,147
Hartley:														
City ---------------	205	Drift -------	----	30	----	----	335	149	304		506	1,522	33	2,626
Hull:														
City ---------------	1,256	Algonkian --	18	----	6	5	322	124	192	23	384	1,380	33	2,295
Knoxville:														
Hospital for Inebriates --------------	326	Des Moines--	10	----	0.4	3	303	52	436		262	1,600	18	2,553
Moulton:														
Electric Light Co.	400	---- do. ----	7	----	2	1	350	77	373	8	170	1,764	20	2,687
Ogden:														
City ---------------	2,800	-------------	10	----	7	4	139	60	231		270	736	59	1,381
Nevada:														
City ---------------	980	Maquoketa -	9	----	5	2.5	426	84	141	19	315	1,390	42	2,276
Sanborn:														
Chicago, Milwaukee & St. Paul Ry.	1,230	Cambrian --	----	----	----	----	353	114	182		458	1,282	26	2,186
Sac City:														
Canning Works ----	378	-------------	14	2	----	----	192	60	257		434	874	7	1,623
State Center:														
City ---------------	161	Drift -------	22	14	----	----	363	136	341		1,062	1,254	7	2,668

[a] Sum of the radicles minus one-half the bicarbonate radicle.

CALCIC SULPHATED ALKALINE-SALINE WATERS.

The waters of this class are not numerous, fewer than 25 having been found during this study; they contain large amounts of calcium and sulphates and less than 100 parts of either sodium or chlorides. With one or two exceptions they come from shallow wells, usually in the drift. They contain in largest proportion the substances that cause hardness, and they are the most difficult and expensive waters to soften. In proportion to their mineral content they produce the largest amount of boiler scale, of the type most difficult to remove.

They are, therefore, the least desirable waters for domestic and economic uses in general, considered from the standpoint of their mineral content only.

The following table includes nearly all the very good examples of this class of waters.

Analyses af calcic sulphated alkaline-saline waters in Iowa.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids [a]
Belle Plaine: City	193	Drift	2	----	6	0	504	201	38		334	1,814	6	2,738
Belle Plaine: City	1,520	Oneota	22	----	1	3	346	135	72	11	268	1,247	9	1,980
Bancroft: Chicago & North Western Ry.	438	----	3	2	----	----	180	65	93		436	518	11	1,090
Chelsea: City	100	Drift	15	----	5	2	489	204	38		240	1,923	7	2,803
Lake Park: City	98	do.	32	----	7	5	316	105	32		513	833	4	1,590
New Hampton: Chicago, Milwaukee & St. Paul Ry.	188	Devonian	----	3	----	----	219	50	24		456	366	33	923
Primghar: J. J. Shonts	372	Drift	29	----	11	7	375	156	51		570	1,199	7	2,120
Prairie City: Chicago, Rock Island & Pacific Ry.	360	Carboniferous.	----	36	----	----	331	126	41		662	1,110	5	1,980
Spirit Lake: City	100	Drift	27	----	2	1	213	52	52		463	433	20	1,031
Stark: Chicago & North Western Ry.	40	do.	14	----		2	374	139	75		410	1,262	6	2,277
Toledo: County Home	545	Devonian	11	----	3	2	275	144	64		251	1,119	7	1,750
Vining: City	235	Mississippian	----	3	----	----	348	135	46		263	1,244	7	1,914

[a] Sum of the constituents minus one-half of the bicarbonate radicle.

CALCIC CARBONATED ALKALINE WATERS.

Nearly all the best waters of the state belong to the calcic carbonated alkaline class. The amount of bicarbonate does not vary greatly; with a few exceptions, as at Manson, it is not less than 200 parts and in few places does it exceed 450 parts, if some old analyses are discredited, because the chemist apparently has assumed the presence of enough carbonic acid to combine with the bases. In a few waters, as at Davenport, Logan, and Williamsburg, there is not enough calcium and magnesium to combine with the bicarbonates, but in most of the waters that is not the condition. The amount of bicarbonates in waters of this class is about the same as that in more strongly mineralized waters; therefore, the waters high in mineral content may be regarded as waters of this class plus sulphates and more calcium or plus sulphates and chlorine and more calcium, magnesium, and sodium, till the most highly mineralized and most complex waters are formed. Waters of this class are the better the more nearly they approach the ideal type, in which their hardness is almost entirely temporary. They lose their bicarbonates when boiled and to a great extent when exposed to the air. They do not give the hard scale formed by the calcium sulphated waters.

In the examples given total solids seldom exceed 400 parts. Sodium is less than 20 parts. The sulphate and chlorine radicles are low and are practically insignificant. Examples could be greatly multiplied without including waters having more than 50 parts of any one of these three radicles. Waters of this character are most numerous in the northeastern part of the state, to which reference has been made as the region having the best deep-well waters. Such waters are less numerous in other parts of the state, though in some places they are obtained from the sands of the drift and from river bottoms. Though wells supplying such waters may pentrate rock for short distances, it is probable that they derive their waters chiefly from drift gravel and sand just above the rock.

Analyses of calcic carbonated alkaline waters in Iowa.

(Parts per million.)

Locality and Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids *a*
Ackley: Mrs. John Carroll	----	Mississippian	24	----	3	1	72	25	19		402	0	1	346
Boone: City	50	Drift	27	----	1	1	101	34	12	3	450	1	4	409
Dubuque: Chicago, Milwaukee & St. Paul Ry.	1,262	Dresbach or underlying Cambrian sandstone	----	----	----	----	56	33	9		332	18	7	284
Eldora: City	200	Des Moines	10	----	1	0.2	55	24	14	3	300	0	2	259
Lake Mills: Chicago & North Western Ry.	----	Devonian limestone.	17	----	----	2.9	87	28	5		406	8	1.5	352
Manchester: Spring, U. S. Fish Hatchery.	----	----	10	----	----	1	50	20	6	1	207	11	4	206
Mason City: City No. 3	651	Galena and Platteville.	9	----	5	1.3	81	34	14	5	423	11	5	377
Mount Vernon: City	330	Niagaran	21	3	----	----	53	30	9		298	7	14	286
Morley: Chicago & North Western Ry.	214	do.	----	4	----	----	72	25	6		346	10	2	292
Northwood: City	87	Devonian limestone.	18	----	.3	0.5	74	24	8		318	1.5	8	293
Stanwood: Chicago & North Western Ry.	116	----	8	2	----	----	71	26	11		368	3	0	305
Sabula: City	973	Oneota	3	6	----	----	54	32	14		337	21	0	298
Tipton: City	2,696	Cambrian or Algonkian sandstone.	15	----	----	1	82	26	12	1	378	4	2	332
West Union: City	70	----	----	8	----	----	75	24	11		348	9	10	306

a Sum of the constituents minus one-half of the bicarbonate radicle.

SODIC-CALCIC CARBONATED ALKALINE WATERS.

The waters of the sodic-calcic carbonated alkaline class are not numerous, and the following table contains nearly all wnose analyses have been procured. Those selected have not enough sulphates and chlorine to combine with the sodium and potassium.

Analyses of sodic-calcic carbonated alkaline waters in Iowa.

(Parts per million.)

Locality	Owner	Depth of well in feet	Name of Lowest Stratum	Silica (SiO_2)	Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	Iron (Fe)	Aluminum (Al)
Brooklyn	City	180		13		0.6	0.5
Ellsworth	W. H. Brinton	91	Drift	14		5	1
Holland	L. Beenken	344	Mississippian	15		.4	2
Grand Junction	Chicago & North Western Ry. Co.	300	Des Moines	9	1		
Shannon	Chicago Great Western Ry. Co.	35					
Stanhope	Ole Satre	328	Carboniferous	21		3	0.2
Sumner	City	1,740	St. Lawrence	8		1	1
Williamsburg	do.	95					1
Do.	Hughes' well	195			10		
Washington	City	232					

Locality	Owner	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate radicle (HCO_3)	Sulphate radicle (SO_4)	Chlorine (Cl)	Total solids [a]
Brooklyn	City	47	18	120	4	432	87	2	509
Ellsworth	W. H. Brinton	59	28	46	4	440	0	0.4	377
Holland	L. Beenken	56	33	97		457	26	2	460
Grand Junction	Chicago & North Western Ry. Co.	70	26	67		502	0	6	430
Shannon	Chicago Great Western Ry. Co.	18	15	161		388	154	9	551
Stanhope	Ole Satre	106	39	99		473	54	4	563
Sumner	City	43	20	63	9	353	8	4	334
Williamsburg	do.	57	19	106		536	2	6	459
Do.	Hughes' well	47	15	97		473	0	2	407
Washington	City	33	13	194		558	54	25	598

CHAPTER VIII.

UNDERGROUND WATERS OF THE NORTHEAST DISTRICT.[1]

INTRODUCTION

BY W. H. NORTON.

The northeast district of Iowa comprises the eleven counties of Allamakee, Bremer, Black Hawk, Buchanan, Chickasaw, Clayton, Delaware, Dubuque, Fayette, Howard, and Winneshiek. In no other part of Iowa are geologic structure and artesian conditions better known than here, and in none are artesian forecasts more sure and favorable. In the extreme northeastern part of the district the Jordan, New Richmond, and Saint Peter sandstones outcrop at the surface, and the Dresbach sandstone lies near the surface in the deepest valleys. Thus the deepest water-bearing beds come to or near the surface, and nowhere do they lie so deep as to be beyond easy reach of the drill. Artesian wells can be sunk so cheaply that they can be afforded as public supplies by all except the smaller towns and villages. The water supply is abundant and suffices for any but the largest cities, and it ranks in quality among the finest drinking waters of the United States.

The strata incline gently toward the southwest, their maximum descent being at right angles to their strike. Thus from Lansing to Sumner (56 miles) the summit of the Jordan declines 1,018 feet, or 18 feet to the mile. To the west and to the south across the area the decline is less. Thus from McGregor to Charles City (75 miles) the summit of the Jordan falls 833 feet, or 11.1 feet to the mile; from Postville to Charles City (55 miles) the St. Peter falls 532 feet, or 9.1 feet to the mile. (See

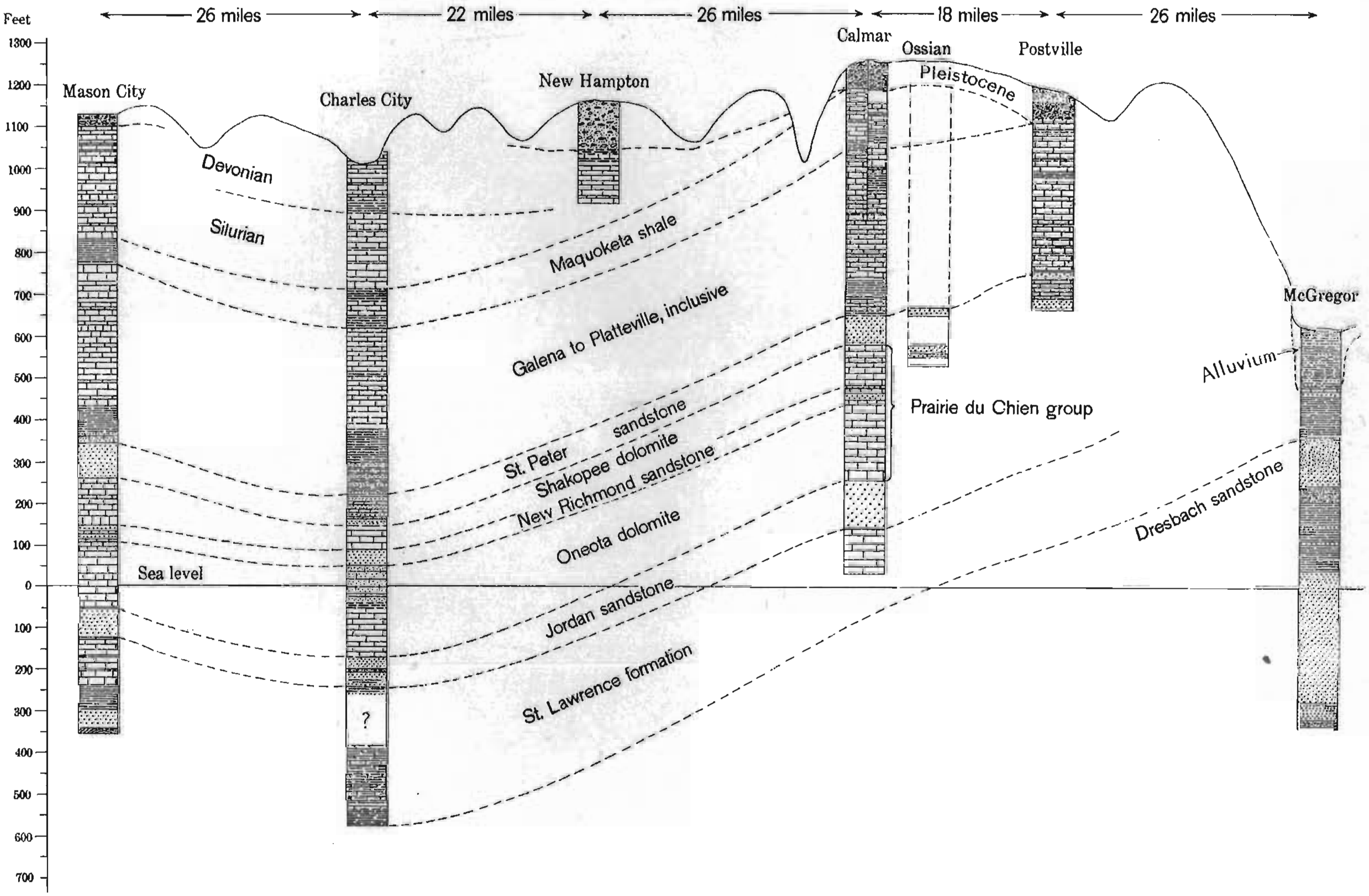
[1]Counties in each district arranged alphabetically.

Pl. V.) Along the southern edge of the area from Dubuque to Waterloo (84 miles) the dip is more gentle, the Jordan falling 5.8 feet per mile and the Saint Peter 5.5 feet to the mile. (See Pl. VI.) The descent is most rapid in the eastern part of the district, the Jordan dipping 10.4 feet to the mile from Dubuque to Manchester, and but two feet to the mile from Manchester to Waterloo. A similar descent occurs from Sumner to Waverly. Probably both Waterloo and Waverly lie on or near a low upwarp which interrupts in part the normal southwesterly dip. If this is the case, the upwarp either dies out toward the north, since at Charles City the sag of the strata is marked, or its axis is directed to one side of that city. From Charles City to Waverly the Jordan sinks but 45 feet and the Saint Peter rises slightly. Though the direction is here parallel with the strike, the slight fall is in contrast with the marked decline of the strata both from Osage to Charles City and from Waverly to Waterloo. (See Pl. VII.)

Except in the extreme east and northeast sections, artesian wells should not be carried below the base of the Jordan sandstone. Considerable money has been spent in useless drilling below the Jordan. Thus at Waverly the drill penetrated 480 feet of the dolomites and shales of the Saint Lawrence formation and at Sumner 460 feet. At Manchester the well was drilled more than 550 feet below this main water bed and, although the Dresbach was here reached, it was found dry as far as penetrated. The Oelwein city well seems to have been stopped before it reached the Jordan and might advantageously have been drilled deeper.

In the valley towns of Allamakee and northern Clayton counties the Dresbach and underlying sandstones are easily accessible and will yield an abundant supply of water. In Dubuque county, along Mississippi river, the Dresbach and underlying sandstones are most valuable water-bearing beds. At Dubuque some of the deepest wells not only tap the Dresbach but, passing through subjacent shaly beds, draw large quantities of water from a still deeper Cambrian sandstone.

On the uplands of the eastern counties the smaller towns and villages may obtain sufficient water from the Saint Peter, as



GEOLOGIC SECTION BETWEEN McGREGOR AND MASON CITY, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

in the wells at Postville and Monona. Although the water will stand low in the wells, its supply seems to be fairly ample, notwithstanding its escape where the formation is cut by the valley sides.

Flowing wells may reasonably be expected for considerable distances up the valleys whose floors lie not far above the Saint Peter, as those of Turkey and Volga rivers. (See also p. 288.)

The artesian resources are best developed at Mason City, McGregor, and Dubuque. Even in the most favorable artesian sections, however, the ground-water resources are comparatively undeveloped. (See Pl. I, in pocket.) Two counties are without deep wells, and the number of the deeper sort of shallow wells is comparatively small. Development must come as the population and towns of this region grow. The evidence seems to be that for a long time this region will have a practically unlimited source of supply of good water for any probable population. Not the least of its good fortune lies in the fact that all ground waters seem to be about equally good from the point of view of mineral content. The problem of casing is reduced to its simplest terms, for it is only necessary to put down casings to solid rock to and through caving shales. There are no deleterious waters to case out, and as the upper waters are comparatively soft the matter of the rusting out of casings is not to be so much feared as it is in other sections of the state.

ALLAMAKEE COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

Allamakee, the northeasternmost county of Iowa, lies almost wholly in the driftless area. The region is a deeply and intricately dissected upland, attaining an elevation of 1,300 feet above sea level, and rising about 700 feet above Mississippi river, which forms the eastern boundary of the county. The valleys of the streams are flat-floored and wide. The Mississippi flood plain attains a width of four miles and embraces a maze of sandy islands and braided bayous. The floor of the valley of the meandering Upper Iowa river has a general width of three-quarters of a mile, widening in its lower course to a mile and more. The valley of Yellow river is narrower but conforms to the same general type. The tributary creeks have well-opened mature preglacial valleys, and the courses of even their wet-weather affluents are graded.

The topographic age of the region is best read in the semicircular coves carved by the ancient stream on both sides of the valley of Upper Iowa river. These deep amphitheaters are guarded at their entrances by lofty isolated buttes, remnants of the rock spurs cut by the stream as it entrenched its curving course. No such coves and buttes are seen along the bluffs of the Mississippi, though the succession of strata is equally favorable to cliff recession and planation, the vast volume of water of the latter stream in Pleistocene times having cut back any salients of the valley sides and left a wall of rock singularly continuous and even and sweeping in its curves.

The interstream areas consist of parallel east-west ridges or uplands, whose summits, where broadest, are cut by shallow valleys into a gently rolling topography. Their dissected flanks consist of lobate ridges of sinuous crest whose steep sides are gashed by deep ravines.

The summits of the divides rise to a common level. If the valleys could be filled with the material that has been swept away by running water they would constitute a plain whose origin may be ascribed to long subaerial erosion near the level of the sea. An additional proof of the former existence of this ancient peneplain, of which the summits of the divides are the remnants, is found in the valuable limonite and hematite deposits of Iron Hill on the crest of Waukon Ridge. Such deposits are common on peneplains where the rocks have long been wasted by slow decay.

Some evidence of a second and lower erosion plain is seen in the accordant level of the long lateral spurs that seperate the valleys of the creeks tributary to Upper Iowa river. The crests of these spurs, which are capped by the Saint Peter sandstone, fall into a common plane about 1,100 feet above sea level, and thus lie distinctly below the level of the upland. Measured by the distance between the escarpments of the Galena and Platteville limestones of the upland, the width of the valley floor of the Upper Iowa, developed 1,100 feet above sea level, was about 10 miles. In age the planation of this valley floor would seem to correspond with that of the similar peneplain of the second generation developed at Dubuque on the weak Maquoketa shale. In each place, however, another explanation may be found in cliff recession under weathering. In Allamakee county the Galena-Platteville escarpment may be supposed to have retreated because of the weak Saint Peter sandstone on which it rests and which caps the ridges defining the 1,100-foot level; and in Dubuque county the Niagaran escarpment may be held to have receded in a similar manner because of the undermining of the immediately subjacent Maquoketa shale.

GEOLOGY.

The rocks underlying Allamakee county dip slightly toward the southwest. (See Pl. V.) They are also bent in one or more comparatively narrow low northwest-southeast folds. As a result of the southwestward dip the oldest rocks are exposed in the northeastern part of the county along the base of the bluffs bounding the deepest valleys, and the youngest rocks along the crests of the divides in the southwestern parts of the county.

The main valleys have been cut considerably deeper than their present floors and are built up with alluvium, probably Pleistocene in age. Thus the wells at New Albin strike rock only at from 130 to 140 feet from the surface, or more than 100 feet below the present river levels. Moreover, old terraces, remnants of ancient flood plains, standing as high as 60 feet above the rivers, mark the height at which the streams of the region ran when they ceased aggrading their rock-cut valleys and began the task of degradation.

The highest beds of the county (Ordovician) are limestones and shales belonging to the Galena, Decorah, and Platteville formations. The Galena is composed chiefly of limestones which may be dolomitized in whole or part. The combined thickness of the three formations varies within wide limits. On Waterloo Ridge it does not appear to exceed 100 feet; at Postville (Pl. V) it was found to be 364 feet thick in the city well;

at Waukon the city deep well found the base of the Platteville 195 feet below the surface.

Beneath the Platteville limestone is the Saint Peter sandstone, white and incoherent, or locally stained and hardened by exposure at the surface, its grains uncemented, rounded, and fairly uniform in size in any stratum and locality. Its thickness is reported as about 80 feet. It contains practically no interstitial filling, and water seeps as freely through it as through a bed of incoherent sand.

Underlying the Saint Peter sandstone is a thick body of dolomites, known as the Prairie du Chien stage, which forms the basal part of the Ordovician. Crowning with white castellated cliffs many a bold bluff along the river courses the Prairie du Chien stage forms the most conspicuous terrane within the county. Toward the summit of the stage sandy beds, known as the New Richmond sandstone, divide this body of dolomite into an upper formation called the Shakopee dolomite and a lower formation known as the Oneota dolomite. The Shakopee, and to a less extent the Oneota also, includes much silica in sandy layers, disseminated grains, and masses of chert.

Transition beds of limy sandstone and sandy limestone connect the Prairie du Chien with the underlying Jordan sandstone (Cambrian), whose thickness is nearly 150 feet. The Jordan is composed of well-rounded grains of pure quartz sand and in most places is soft and friable. Some layers, however, are well cemented. Where exposed to the weather the Jordan is gray or yellow, although its normal color, as seen in well drillings, is white.

The Jordan sandstone resembles the Saint Peter in composition, but because of its greater depth beneath the surface it is less thoroughly drained; because of its greater and more uniform thickness its supply is more abundant.

The Jordan sandstone rests on a formation composed of sandy dolomites, limy sandstones, and sandy and limy shales—the Saint Lawrence. These rocks are exposed in the cliffs bordering the Mississippi and its tributaries and are so argillaceous that they are generally dry. They form an impervious floor for the waters of the Jordan, and, where they lie deepest, prevent the rise and escape, under hydrostatic pressure, of the waters of the underlying Dresbach and earlier Cambrian sandstones.

The relations of the Saint Lawrence and the underlying Cambrian terranes are not clearly made out from the evidence at hand. In the cliffs at Lansing the Saint Lawrence, as described by Calvin,[1] outcrops 96 feet above the level of the Mississippi river with a thickness of 44 feet. Beneath it lie gray, yellow, and brown friable sandstones measuring 56 feet, containing greenish layers and near the top argillaceous beds. The underlying strata to the river level, a distance of 40 feet, are concealed from view. The deep well at Lansing continues the section, beginning at 640 feet above sea level, 18 feet above mean water level in the river. Unfortunately the only data obtainable from the well are a tube of drillings which give the succession and the lithologic characteristics of the beds, but nothing as a basis of inference as to the thickness of the strata except the relative space which they occupy in the tube. Estimating the thickness of the terranes in this way we have the following succession of beds pierced by the drill:

Record of deep well at Lansing.

	Thickness Feet.
Surface clay	37
Shales	70
White sandstone	125
Shales with a thin intercalated bed of sandstone	135
Sandstone resting on hard crystalline rock	381

Near New Albin, which is located about 10 miles north of Lansing, Calvin observed at the base of the bluffs a blue calcareous shale. From the New Albin wells we have a single log uncorroborated by drillings. The well section here begins at 650 feet above sea level, 10 feet above the top of the Lansing boring, and is as follows:

Record of deep well at New Albin.

	Thickness Feet.
Sand and gravel (alluvium of Mississippi)	130
Soapstone	150
Sandstone	190

[1]Ann. Rept. Iowa Geol. Survey, vol. 4, pp. 57-59.

New Albin and Lansing are nearly aligned with the strike of the strata. At New Albin the base of the Oneota dolomite is placed by Calvin at 320 feet above the tracks of the Chicago, Milwaukee & St. Paul railway (966 feet above sea level) and at Lansing at 300 feet above the river (918 feet above sea level), giving a southward dip of about five feet to the mile. Correlating the two sections it would seem possible that the shale at the base of the bluffs at New Albin is the same as the first shale in the Lansing well. The first sandstone of the Lansing well is then cut out by the ancient channel of the Mississippi at New Albin, and the first shale (soapstone) of the New Albin log is identical with the second shale at Lansing, with which it also agrees in color and estimated thickness. The base of this shale at New Albin is about 100 feet higher than at Lansing, according to the estimates. The known southward dip of the strata accounts for half of this amount and the remainder is perhaps included in the margin of error in estimates of the thickness of the beds resting on the exceedingly precarious foundations already mentioned.

The thickness of 44 feet assigned by Calvin to the Saint Lawrence at Lansing is far less than that of the dolomites and shales intervening between the Jordan sandstone and the first sandstone beneath it, as shown in deep-well sections. Even if all of the 40 feet of concealed strata above the Saint Lawrence in the Lansing bluffs belong to that terrane, it still compasses not more than one-third of the thickness common in deep-well sections.

On the whole it seems very possible that the equivalent of the Saint Lawrence of the deep-well sections includes at Lansing all the strata between the St. Lawrence of Calvin and the level of the river and also the first shale disclosed in the deep wells. Its total thickness might then reach 230 feet, but this would not be more than that of the formation at Manchester and Anamosa, and but 30 feet more than that given in an imperfect record at Dubuque. The shale at the foot of the bluffs at New Albin would then be assigned to the same terrane.

Under this interpretation of the Saint Lawrence the white sandstone first to be found in the Lansing well is the probable equivalent of the Dresbach sandstone of Minnesota, and the underlying shale and sandstone are undifferentiated Cambrian. On the other hand, if Calvin's limitation of the Saint Lawrence be correct, the Dresbach outcrops beneath it from Lansing to New Albin.

UNDERGROUND WATER.

SOURCE.

On account of the intimate dissection of the upland, the water-bearing rocks are cut by valleys and ravines and their waters find easy terminal escape. Ground water stands low, wells are deep, and the windmill is a conspicuous feature of the farms.

The Galena dolomite and Platteville limestone have for long ages been subject to the solvent action of ground water. Numerous sink holes pit the surface and lead to well-defined subterranean waterways, which have been opened by solution along joint and bedding planes. Unfortunately, neither the depth nor the position of these watercourses can be predicted. The beds of impervious shale in the Platteville arrest the downward progress of the water, which issues as springs where the valley sides intersect the surface of the shale and which forms the chief supply of wells sunk to it.

Wherever the drill goes deep enough to strike the Saint Peter sandstone water is found, except at or near the edges of the bluffs where the formation outcrops. The head of the water is low owing to its easy terminal escape, but the supply is plentiful.

The Prairie du Chien stage, with its creviced dolomites and included sandy beds, forms a capacious reservoir for underground water and greatly augments the supply of most wells penetrating it.

The Jordan sandstone contains abundant water, which is prevented from escape by the impervious floor formed by the Saint Lawrence formation.

The Cambrian sandstones underlying the Saint Lawrence formation hold vast quantities of ground water. The Dresbach (thus designating the first sandstone of the Lansing well) holds water of the same quality and head as that of the sandstone beneath it, but of less copious flow. The lower sandstone, from which the Dresbach is parted by heavy shales, supplies the New Albin wells.

UNDERGROUND-WATER PROVINCES.

Mississippi Valley.—The Mississippi valley may be considered a special underground-water province. The unusual width of the flood plain and the materials of which it is composed have already been mentioned. The area is used chiefly for pasture and the few wells needed find water within a score of feet from the surface.

Upper Iowa Valley.—The Upper Iowa valley is a wide and fertile lowland, well watered by springs issuing from the hillsides. Nevertheless, flowing water is obtainable so easily and in such large quantity that within the last decade several artesian wells have been sunk through varying depths of alluvium to the underlying Cambrian sandstones. At New Albin, at the mouth of the valley, the alluvial filling is reported to be 134 feet thick, and eight miles up the valley it is still 100 feet thick. Wells near the bluffs find rock at less depth. The rock first struck is blue or green, dry, shaly or dolomite sandstone. Its thickness ranges from 110 to 190 feet. Beneath this blue or greenish rock lies what is described as a white "sand rock" in whose more porous layers abundant water is found under strong artesian pressure. The depth to which this sandstone has been penetrated ranges from 30 to nearly 300 feet. The head of water in wells 5 to 10 miles up the valley is about 690 feet above sea level, the water rising about 10 feet above the curb. Still farther up the valley, in Union City township, the water in a well owned by J. H. Beardmore heads 15 feet above the curb, discharging from a 5¾-inch casing at a rate of 100 gallons per minute. These wells are all cased to solid rock, a distance commonly of more than 100 feet. The abundance of pure water obtained and the saving of labor and cost of pumping make these wells comparatively inexpensive, wells of 300 feet deep having been sunk at a cost, including casing, of $225. A list of these wells is appended.

Flowing wells in the Upper Iowa (Oneota) Valley, Allamakee County.

Owner	Locality	Depth	Diameter	Depth to rock	Depth to water supply	Source of supply	Head above curb	Remarks
		Feet	Inches	Feet	Feet		Feet	
J. H. Beardmore	----	252	5⅝	----	160	----	15	Cased to 98 feet. Yields 100 gallons per minute.
Otto Bateen	----	350	4	----	----	----	----	
J. T. Bullman	----	350	4	----	----	----	----	
J. L. Dirth	----	400	4	----	----	----	----	
Thomas Rekurn	----	480	4	----	----	----	----	
E. J. Sadler	----	260	4	----	----	----	----	
M. Sadler	----	250	4	----	----	----	----	
T. 100 N., R. 5 W. (Union City)								
Ed. Bellows	SE. ¼ sec. 36.	490	----	----	----	----	----	
B. Hartley	NE. ¼ sec. 34.	300	4	----	145	Sandstone	8	Curb 20 feet above river. Cased to 112 feet. Yields 20 gallons per minute.
J. Hartley	— — sec. 34.	490	4	60	40	do.	4	Cased to 80 feet.
James Kibby	SW. ¼ sec. 35.	618	----	----	----	----	----	
T. 100 N., R. 4 W. (Iowa)								
Nicholas Colch	SW. ¼ sec. 28.	524	----	----	----	----	----	
George Myers	SW. ¼ sec. 20.	330	----	----	----	----	----	
P. S. Pierce	SE. ¼ sec. 25.	340	4	80	300	----	2[illegible]	
J. H. Riser	SW. ¼ sec. 11.	550	8	----	----	----	----	
Frank Weymiller	SW. ¼ sec. 10.	450	6	----	----	----	----	
Louis Weymiller	NW. ¼ sec. 10.	414	4	53	26	Sandstone	9	Curb 23 feet above river. Cased to 20 feet. Yields 15 gallons per minute.

Minor Valleys.—The floors of the valleys of Clear, Village, and Paint creeks, and of Yellow river are narrower than the valley floor of the Upper Iowa, and the bordering terraces are relatively wider. These high remnants of ancient flood plains are naturally rather dry, as ground water readily escapes along their scarps. The streams are spring fed and permanent, and the springs issuing along the valley sides greatly lessen the need for wells. In Clear creek and Village creek valleys artesian wells furnish water for mills. Wells sunk in the wider bottom lands of Yellow river will probably obtain flowing water.

From Myron to Ion the stream flows successively over the Platteville limestone, the Saint Peter sandstone, and the dolomites and sandstone of the Prairie du Chien stage, and wells reaching the Jordan sandstone should yield a generous flow. At present dug and driven shallow wells furnish the chief supply.

Uplands.—On the uplands, as on all maturely dissected areas of high relief, permanent and abundant ground water lies at a considerable depth below the surface. On the high ridge north of Upper Iowa river, back of New Albin, farm wells commonly exceed 300 feet in depth. Below the surface yellow loam (loess) and the underlying reddish residual clays, wells enter a limestone of the Prairie du Chien stage, pass thence into a water-bearing sandstone (the Jordan) and traversing a "blue rock shale" (the Saint Lawrence) find abundant water in the Dresbach sandstone. As the Jordan outcrops along the river bluffs its waters easily escape and have low head, but the water of the Dresbach is under sufficient head to bring it in some wells within 285 feet of the surface. The following log of a well on this ridge, belonging to Henry Rink (NW. ¼ sec. 26, T. 100 N., R. 5 W.), is probably representative:

Section of Rink well, Allamakee county.

	Thickness Feet	Depth Feet
Surface deposits	40	40
Limestone (Prairie du Chien)	135	175
Sandstone (Jordan)	100	275
Shale, blue (Saint Lawrence)	200	475
Sandstone (Dresbach)	35	510

Water is found chiefly in the Dresbach; it commonly stands 225 feet below the surface.

On Waterloo Ridge in the extreme northwestern part of the county accurate surface measurements by Calvin give the following thicknesses to the formations there present:

Thickness of formations on Waterloo Ridge.

	feet.
Galena dolomite, Decorah shale, and Platteville limestone	100
Saint Peter sandstone	80
Prairie du Chien stage	250
Jordan sandstone to level of mouth of Bear creek ....*....	100

Water may be found in the Galena dolomite and in the Platteville limestone, especially above the basal shales of the Platteville if the drill strikes a water-bearing crevice, and in the Saint Peter and Jordan sandstones.

On Gruber Ridge and May Prairie and on the summits of the lobate ridges whose crests are formed of the Saint Peter sandstone, much the same conditions prevail as north of Upper Iowa river. Loess and residual clay may reach 40 feet in thickness; the Prairie du Chien stage is reported in some wells as 160 feet, and the Jordan sandstone as 100 feet, underlain by "blue rock" (Saint Lawrence formation).

On the wide uplands about Waukon and Postville the Galena dolomite and the Platteville limestone yield water to farm wells 75 to 125 feet deep. House wells at Waukon are commonly sunk about 80 feet and end in the Platteville. At Postville some wells obtain water in glacial gravels underlying blue-black till at a depth of 85 feet; others obtain water in the Galena dolomite or the Platteville limestone within 150 feet of the surface. For larger supplies than ordinary, and where the drill fails to find a water channel in the limestone, wells on these uplands must go to the Saint Peter or, in some localities, to the Jordan. The depth of these sandstones varies with the southward and westward dip of the strata The Saint Peter, for example, outcrops at Radcliffe, one mile north of Waukon, at 1,122 feet above sea level; eight miles south of Waukon it has descended to the valley floor of Yellow river, 872 feet above sea level.

The well, 600 feet deep, of the county farm near Waukon, on high ground, found some water in the Galena dolomite or the Platteville limestone, the water rising to 57 feet below the surface. In the sandstones, which, according to the drillers, were struck at 400 and 500 feet, the water fell, that from the lower sandstone standing 240 feet below the curb.

An exceptionally reliable log of a well northeast of Postville, in the NW. 1/4 NW. 1/4 sec. 21, T. 96 N., R. 5 W., is no doubt typical of the deeper wells of the southwestern townships. The curb is not far from 1,100 feet above sea level.

Log of well northeast of Postville.

	Thickness Feet	Depth Feet
Clay	24	24
Dolomite (Galena)	50	74
Limestone (Galena)	150	224
Shale (Plateville)	66	290
Sandstone (Saint Peter)	31	321

A strong vein of water was found in the Saint Peter at 318 feet, but it rose only eight feet in the well.

SPRINGS.

No area of equal size in the state is so bountifully supplied with springs as in Allamakee county, the principal source being at the contact of the Decorah shale with the overlying Galena limestone. Where the Galena forms the bedrock of the uplands, the ravines on the south side of the ridges are dry only down to where they cut this heavy shale. Here copious springs gush out from the rock and here begin countless rivulets which flow down the hillsides to feed the creeks and rivers. Where the roads follow the ravines farmhouses are commonly located along the Galena-Decorah contact in close proximity to springs, which afford, without cost, pure water for all household uses. Spring houses are built over them for dairy purposes, and the water, flowing in a brook several feet wide through the barnyard, conveniently supplies the needs of the stock. Where the farmhouse is at a lower level than the spring, water can be piped through the house under pressure and used for all domestic purposes, including refrigeration. It may also be sufficient in quantity and head to furnish water power to drive a separator, churn, or other light machinery. Many springs emerge at the base of ledges of Galena that outcrop high up on the sides of narrow and deep ravines. Picturesque as are these cascading springs, they are generally too remote from farmsteads for utilization. The August temperature of several springs from the Galena-Decorah contact ranges from 46° to 47° F.

The Livinggood spring, the largest in the county, flows from the Galena-Decorah contact near Myron (NW. ¼ SW. ¼ sec. 3, T. 96 N., R. 6 W.), emerging where the floor of the valley of

Yellow river crosses the summit of the Decorah shale. On the left bank a group of springs at the base of a semicircular alcove, with vertical walls of rock cut in the side of the bluff, unite to form a swift-running stream a foot deep and a rod wide. Up valley from this spring Yellow river carries but little water except from the run-off at times of rain, since its channel lies above the chief spring horizons. In August, 1906, the water running in the river bed up the valley from the spring was but a very small fraction of the amount contributed by the spring. The summer temperature of the spring at its outflow is about 48° F.

This spring is known in the vicinity as the Rise of Yellow river from the popular belief that up the valley the water of the river sinks from sight and here rises again to the light of day. It is possible that some water of the river may be lost in the opened joints of the limestone over which it flows in its upper course, and any water leaking from the river bed would no doubt form an underflow upon the surface of the next subjacent shale, though not necessarily in a course immediately beneath the river channel or, indeed, beneath the river valley. But the larger part, if not the entire amount of the discharge of the spring, is in all probability drawn from the underground water of the upland to the north, which here finds issue where the main horizon of its seepage is first intersected by the valley of the river.

Springs occur also near the base of the Saint Peter sandstone, but these are neither so numerous nor so large as those from the summit of the Decorah shale. The Saint Peter lies upon a creviced limestone, through which its waters can seep to lower drainage levels. Moreover, the massiveness of the sandstone, its lack of crevices, and the absence of solution channels in this insoluble rock, make against the concentration of water in definite underground courses issuing in strong springs.

The outcrops of the Prairie du Chien in the northern part of the county are marked by large springs which issue near the plane of contact with the Jordan sandstone, as near Quandahl and Dorchester.

The sandstones underlying the Prairie du Chien supply a large number of powerful springs where they are transected by the valleys. They include along with their permeable water beds other layers intermixed with clay and lime, which are far less porous and which serve to hold ground water upon their surfaces and prevent its leakage either downward under gravity or upward under hydrostatic pressure.

In the valleys of the Upper Iowa river and of Mill and Village creeks and in the valleys of their tributaries springs from these sandstones are very numerous. The temperatures measured range from 45° to 49° F., the higher temperatures probably indicating the influence of the summer sun and air on the surface rock waste through which some springs find issue, and on the water of the pool of the spring.

The list of strong springs is too long for publication, but mention may be made of those at the mouth of Paint creek, at Waukon Junction, which discharge near the level of Mississippi river from the waste-cloaked foot of the bluff on the north side of the valley, along a line of about 100 feet. Typical springs also are the M. Gordon springs, three miles southwest of New Albin, in the Upper Iowa river valley; the Jacob Knupf spring, in sec. 24, T. 100 N., R. 6 W.; the Dorchester creamery spring, which supplies the creamery and five buildings of the village; the L. C. and C. C. Megordon springs, near Elon; and the Peter Lang spring, on Village creek, in the NE. 1/4 sec. 7, T. 98 N., R. 3 W., which flows a swift stream with a cross section of 2 1/2 square feet.

CITY AND VILLAGE SUPPLIES.

Lansing.—Two six-inch artesian wells, 675 and 748 feet deep, respectively, were drilled by Swan Bros. in 1877 for the city of Lansing (population, 1,542). The curbs are 640 and 660 feet above sea level. The water originally rose to 690 feet above sea level, and for 20 years and more the pressure continued sufficient to render pumping unnecessary for the delivery of water to the taps. Since 1897 pumps have been installed and a gravity system from a reservoir is used to supply the upper portions of the town. The head has lowered to 35 feet, and the discharge, estimated at first at 700 gallons a minute, has fallen to 300 gallons. The temperature of the water is 50° F. The quality of this water is indicated by the analysis on page 168. The water is distributed under gravity pressure of 95 pounds through three miles of mains to 17 hydrants and 150 taps.

The following record of strata in the 748-foot well is based on drillings taken from a tube. As the original record was lost, it was assumed that the length of the tube and the thickness of the respective drillings were proportioned to the depth of the well and the thickness of the beds.

Record of strata in Lansing city well. (*a*)

	Thickness (estimated)	Depth
	Feet	Feet
Clay, yellow; no samples	37	37
Shale, chocolate colored, slightly calcareous; some coarse Pleistocene sand intermixed	35	72
Shale, greenish yellow, calcareous, arenaceous, with minute angular grains of limpid quartz	35	107
Sandstone, white, yellow and buff; grains differing widely in size	125	232
Shale, light purplish and drab; arenaceous	15	247
Sandstone, fine, yellow	5	252
Shale, arenaceous, or sandstone, argillaceous; blue-drab, slightly calcareous	70	322
Shale, red, arenaceous, with thin stratum of intercalated drab shale	45	367
Sandstone, light yellow; grains moderately fine, subangular, and rounded	381	748
"Hard crystalline rock." *b*		

a See discussion on pp. 285-287. *b* Driller's report.

The Doehler & Schafer well (depth, 630 feet; diameter, 5⅝ inches) heads 35 feet above the curb. The water flows into a mill race, where it joins water from a creek and not only increases the water power but also prevents the water in the race from freezing even in the coldest weather.

The A. C. Doehler well, on Village creek (depth, 750 feet), was formerly used to furnish power for a woolen mill, but has long flowed into the creek unutilized.

New Albin.—The village of New Albin (population, 588) has no waterworks, but a supply for stores, hotels, and private houses, and fire protection to the business portion of the village is furnished by eight artesian wells, ranging in depth from 470 to 550 feet. The water is reported to rise 30 feet above the curb, or 682 feet above sea level. These wells end in the undifferentiated Cambrian beneath the Dresbach and draw thence their large supply of excellent water.

The A. F. Kuhn well (depth, 500 feet; diameter, 6 inches) is cased to 130 feet. Its curb is 650 feet above sea level and its head, by pressure, 41 feet above curb. Water is drawn from beds at 315 and 470 feet. It was completed in 1900 by Frank Easton, of New Albin.

Log of Kuhn well, New Albin.

(Supplied by driller.)

	Thickness Feet	Depth Feet
Loose sand and gravel (in ancient channel of Mississippi)	130	130
Soapstone, blue	150	280
Sand rock, blue	190	470

The New Albin Co-operative Creamery Company's well (depth, 470 feet; diameter, four inches) is cased to 134 feet. Its curb is 650 feet above sea level, and its head, by pressure, is 39 feet above curb. Water from beds at 315 and 470 feet flows about 100 gallons per minute. It was completed in 1905 by Frank Easton at a cost of $300.

The Arikson & Winnetka well has a depth of 500 feet and a diameter of six inches to 135 feet and four inches thence to bottom. Its curb is 650 feet above sea level and its head, by measurement, 29 feet above curb. Its temperature is 51° F. It was completed in 1902 by Frank Easton.

Other wells of approximately the same depth and of essentially the same characteristics have been drilled at New Albin for J. B. Pohlman, H. Martin, F. C. Meyer, Henry Reiser, W. O. Bock, and H. C. Boyer. There are also a number of flowing wells from the same water bed in the Upper Iowa valley west of New Albin. (See pp. 288, 289.)

Postville.—The deep well from which the supply of Postville (population, 952) is drawn was drilled by Dickison Brothers in 1895. It is $8\frac{3}{4}$ inches in diameter and 515 feet deep and ends in the Saint Peter sandstone. (See Pl. V.) The elevation of the curb is 1,191 feet above sea level; the water heads 250 feet to 300 feet below the curb. Water was found at a depth of 130 feet and stood at this level until the drill reached the depth of 435 feet, at which depth a second vein of water was found. The pumping capacity is 32 gallons per minute. The temperature of the water is 48° F.

Strata penetrated in drilling this well are shown in the following table:

Record of strata in city well at Postville.

	Thickness	Depth
	Feet	Feet
Quaternary (72 feet thick; top, 1,191 feet above sea level):		
Humus	2	2
Loess, yellow	16	18
Loess, ashen	6	24
Clay, yellow, sandy and pebbly, noncalcareous	4	28
Sand, yellow, sharp, and rather coarse	4	32
Clay, dark drab, sandy and pebbly, calcareous	40	72
Ordovician:		
Galena dolomite to Platteville limestone (364½ feet thick; top, 1,119 feet above sea level)—		
Limestone; some buff and magnesian, some lighter color and of rapid effervescence; cherty	13	85
Shale, green, calcareous, soft	12	97
Limestone, blue, earthy, magnesian; 11 samples	106	203
Shale, soft, gray, calcareous	9	212
Limestone, light yellow and white; hard, by driller's record; earthy to crystalline; nonmagnesian, as judged by rapidity of effervescence	138	350
Limestone as above, but a little softer; 5 samples	35	385
Limestone, greenish gray, argillaceous	10	395
Limestone, light yellow-gray, crystalline to earthy; 4 samples	41½	436½
Saint Peter sandstone (78½ feet thick; top 754½ feet above sea level)—		
Sandstone; usual Saint Peter type; grains rounded and smoothed, of limpid quartz, mostly unbroken; with much limestone yellow and gray, rapidly effervescing; in angular sand; no trace of embedded grains in limestone fragments	11½	448
Sandstone as above, but with less limestone	2	450
Limestone, blue-gray, argillaceous, in part macrocrystalline; in flaky chips, largely composed of comminuted fossils; 2 samples	8	458
Limestone and shale, gray, earthy; in chips	5	463
Limestone, light blue-gray, mottled; in flaky chips, compact, crystalline to earthy	7	470
Limestone, yellow-gray, mottled, macrocrystalline to earthy, fossiliferous; in chips; 4 samples	17	487
Limestone, light gray, compact, fine-grained; 4 samples	15	502
Sandstone, calciferous; soluble ingredients form about one-half by weight of drillings; some grains of sand embedded in the minute angular chips of limestone; other fragments show limestone matrix to be large. Limestone yellow-gray and of rapid effervescence; loose in the drillings, and also embedded are many black opaque grains; ferruginous nodules of calcareous clay; and grainlike nodules of pyrite; 3 samples	13	515

From the starting of the drill, the samples were carefully saved at such short intervals that they afford an exceptional geologic section. If the sandstones at 436½ feet and at 502 feet be set aside, the remaining rocks of the section, in texture and chemical composition, are typically middle Ordovician limestones and shales (Galena and Platteville). Both of the sandstones just designated are regarded by Calvin as Saint Peter, and he has suggested that the fifty-two feet intervening between them represent an ancient cavern in the Saint Peter, now filled with shale and limestone broken down and washed in from the overlying Galena and Platteville.[1]

Water is pumped to an elevated tank and distributed under a gravity pressure of 42 pounds to 22 hydrants and 150 taps. The consumption is 20,000 gallons daily.

Postville Junction.—The Chicago, Rock Island & Pacific Railway Company has a track well at Postville Junction whose depth is 361 feet, and diameter eight inches. Its curb is 1,033 feet above sea level. According to the driller's log, the well passes through drift and Galena dolomite, Decorah shale and Platteville limestone from the surface to 340 feet and the Saint Peter sandstone from 340 feet to 361 feet.

Waukon.—Two artesian wells thirty feet apart, drilled by Palmer and Sanbo in 1896 and 1897, supply the city of Waukon (population, 2,025). They are 8½ inches in diameter and 577 feet deep. The curb is 1,279 feet above sea level, and the water rises to 280 feet below the curb. The depth of the wells indicates that they end in the Jordan sandstone. No diminution in yield has been observed in either well, nor has either been overdrawn by pumping. From the last drilled well alone the pump lifts, if necessary, 3,000 gallons an hour. The average consumption is 21,600 gallons a day, the maximum summer consumption reaching 28,800 gallons. Water is pumped to a standpipe 102 feet high and is delivered under gravity pressure through 6½ miles of mains to 65 fire hydrants and 230 taps.

A well drilled by the Missouri Iron Company about three miles north of Waukon reaches a depth of 396 feet, with a diameter of ten inches. Water rises to within 137 feet of the surface. The temperature is 52° F. The cost of drilling was $3.50 per foot. Casing extends to 250 feet. The drillers were Walch & Bahr of La Crescent, Minnesota.

The log of the drillers is as follows:

[1]Am. Geologist, vol. 17, 1896, pp. 195-203.

Drillers' log of the well of Missouri Iron Company, near Waukon.

	Thickness Feet	Depth Feet
Clay	23	23
Sandstone (Saint Peter)	27	50
Limestone (Shakopee)	76	126
Sandstone (New Richmond)	15	141
Limestone (Oneota)	35	176
Gravel (Oneota)	10	186
Limestone (Oneota)	161	347
Sandstone (Jordan)	49	396

Village supplies.—The following table gives data of village supplies in Allamakee county:

Village supplies in Allamakee county.

Village	Nature of Supply	Depth	Depth to Water Bed	Head Above and Below Curb
		Feet	Feet	Feet
Harpers Ferry	Driven wells and springs, both large and small	45-55	50	— 40
Dorchester	Springs; open, driven, and drilled wells	12-70		— 12 to — 16
Maud	Drilled wells	50-200		— 40 to —150
Elon	Cisterns, springs, and wells	100-325	300	—285
Church	Cisterns and wells	290-350		

The following table gives data of typical wells in Allamakee county:

Typical wells of Allamakee county.

Owner	Locality	Depth	Diameter	Depth to rock	Depth to water supply	Source of Supply	Head below curb	Remarks (log given in feet)
		Feet	Inches	Feet	Feet		Feet	
E. Cooper	6 miles northeast of Lansing.	340	-------	40	------	------------	------	Clay, 40; lime rock, 160; sand rock, 100; lime rock, blue, 40.
County Farm	Near Waukon	600	-------	30	400 500	------------	240	Clay, 30; blue "scale rock," 370; sand rock, yellow, water bearing, 30; blue lime rock, 70; sand rock with water, 100; black clay.
F. M. Ivorson	5 miles southwest of Dorchester.	30	1¼	------	15	River sand	------	River bottom; driven well.
I. M. Ivorson	6 miles southwest of Dorchestrr.	30	1¼	------	10	River sand	20	River bottom; driven well.
Erick Gavle	4 miles northeast of Sattre.	90	6	20	60	Rock	30	Valley; about 20 feet above river.
M. O. Nelson	7 miles east of Locust.	407	6	20	390	Sandstone *a*	388	Hill; 400 feet above river.
P. Oleson	6½ miles east of Locust	250	6	8	35	Limestone	220	Can be pumped dry.
William Nelson	6½ miles southeast of Locust.	245	6	9	40	Limestone	210	Hill; 250 feet above river.
Hans Quanrude	6 miles east of Locust.	365	6	10	350	Sandstone	335	Hill; 375 feet above river.
Henry Rink	NW. ¼ sec. 26, T. 100 N., R 5 W., on Wheatland Ridge.	510	-------	40	------	------------	285	Clay, 40; limestone, 135; sandstone, 100; blue shale, 200; sandstone, 35. Another water vein at 260 feet.
D. O'Mally	8 miles south of Dorchester	310	-------	15	------	------------	160	Clay, 15; limestone, 170; sandstone, 125.
Henry King	6 miles southeast of New Albin.	542	-------	75	530	------------	217	Top of ridge, about 1 mile from edge of bluffs. Clay, etc., 75; limestone, 225; sandstone, 30; blue rock shale, 200; sandstone, water bearing, 12.
M. F. Collins	3½ miles north of Harpers Ferry.	242	6	18	------	------------	300	Ridge.
Chicago, Milwaukee & St. Paul Ry.	Postville	85	-------	------	------	Gravel	------	Water bed gravel; penetrated blue-black till.
Creamery	Postville	150	-------	65	------	------------	115	
Dickson Bros.	NW. ¼ SW. ¼ sec. 21, T. 96 N., R. 5 W.	244	6¾	40	190 and 242	Platteville and Saint Peter.	169	Clay, 40; dolomite, 55; limestone, 120; shale, 28; Saint Peter sandstone, 1. Platteville vein, weak. Temperature, 48 deg. F.
John Laud	NE. ¼ SE. ¼ sec. 32, T. 96 N., R. 5 W.	276	-------	------	260 and 273	------------	244	Clay, 20; shell rock, 10; dolomite, 50; limestone, 150; shale, 45; Saint Peter, 1. Chief supply at 273 feet.

a Another water bed at 260 feet.

BLACK HAWK COUNTY

BY MELVIN F. AREY and W. H. NORTON.

TOPOGRAPHY.

Black Hawk county, which lies immediately west of and in the same range with Buchanan county, is crossed diagonally by Cedar river. Its surface is made up chiefly of the valleys of Cedar and Wapsipinicon rivers and their larger tributaries, and the plains of Iowan drift which lie between and on either side of these valleys. Low bluffs rise near the south side of West Fork of Cedar river, and also along the south side of Beaver creek at a varying distance from the streams; they increase in height eastward and merge into the higher and more precipitous bluffs of the Cedar. At Cedar Falls the bluffs sweep away from the river, leaving a level area on which the older part of the city is built. Below the mouth of Dry Run they gradually recede from the river and lose their height and steepness of slope. Beyond Waterloo they maintain a distinct line between the valley and the drift plain for many miles, though at a considerable distance from the river and with marked diminution in altitude.

Between Cedar Falls and Waterloo the Kansan drift features are manifest in rounded hilltops crowned with loess, though Iowan drift appears in thin veneerings in the immediate neighborhood, and many round granitoid bowlders are seen.

Outside of the region above mentioned the Iowan drift plain constitutes the surface of the greater part of the townships of Cedar Falls, Orange, Cedar and Big Creek, and the whole of Black Hawk, Lincoln and Eagle. The last three townships are remote from the river, and, except in the narrow, sinuous channels of a few small streams, show scarcely a scar upon their surface.

North and east of the Cedar the valley plain rises very gradually and as a rule imperceptibly to the general level of the drift plain. It is for the most part three or four miles wide, level and sandy, and was once wood clad, but now much of it has been deforested. Nearly every part of the valley proper has been traversed at some time by the river and many large oxbows are still connected with it at ordinary stages of the water. Narrow, curved bodies of water, locally known as lakes, some of which, as in Cedar township, are two to three miles long and are connected more or less completely, plainly indicate former channels. Depressions of every size, but all similar in shape and trend, are remarkably abundant. At the time of freshets the river not only fills the channels but also occupies much of the intervening valley.

A short distance from the place where the Cedar leaves the county its valley narrows; it is also noticeably constricted at Waterloo. In the northeastern part of the county the entire townships of Union and Washington are in the valleys of the Cedar and its tributaries. The topography of Union township differs materially from that of any other. The winds seem to have had an unimpeded sweep previous to its settlement and to have gathered the sand into dunes of considerable height and extent. The poplars, bur oak, and other trees and shrubs of similar habitat have taken possession of many of these dunes, and all are now covered with vegetation of some kind.

The drainage of the county is accomplished almost wholly by the Cedar river system, though the Wapsipinicon, with its tributary, Crane creek, cuts across the northeast corner.

The Cedar is formed by the union of three nearly equal streams—the Cedar from the north and east, the Shell Rock from the northwest and the West Fork from the west. The Shell Rock and the West Fork, however, unite a mile above their junction with the Cedar. From the latter point, which is within one and a half miles of the north line of the county, the Cedar flows for four or five miles nearly south, then southeast to Gilbertsville, whence it again goes southward for four or five miles, finally bending to the southeast and keeping that direction till it leaves the county. Except for short distances below the dam at Cedar Falls and at Waterloo, its bed is in unconsolidated material. Indurated rocks outcrop in but few places along its banks, even the high bluffs in the neighborhood of Cedar Falls and Waterloo being apparently made up wholly of drift material.

From the west the Cedar receives Beaver, Dry Run, Black Hawk, Miller, Big and Rock creeks; from the east, Elk, Indian and Spring creeks. It is noteworthy that each of these streams approaches the Cedar at nearly a right angle in marked contrast with the tributaries of the Wapsipinicon and the Iowa. The basin of the Cedar is therefore proportionately much wider than that of either of the other rivers named. The headwaters of Spring and Elk creeks are within two miles of Wapsipinicon river and Crane creek, respectively; the Black Hawk takes its rise within five or six miles of the Iowa.

GEOLOGY.

The geologic formations of Black Hawk county are comparatively simple. Heavy deposits of Kansan drift covered by a thin veneer of Iowan drift and in places the intervening Buchanan gravel conceal the hard rocks in the northeastern and southern parts of the county. Rock is exposed mainly along the margins of the valley of the Cedar or outcrops in the banks along the lower courses of its tributaries.

Except in the small area in the southwest corner of the county, where the drift probably rests on rocks belonging to the Kinderhook stage (basal Mississippian), and a small area in the eastern part of Fox township, where it overlies the Wapsipinicon limestone (Middle Devonian), the drift in Black Hawk county is underlain by the Cedar Valley limestone (Middle Devonian). The rock is everywhere limestone, though in places very shaly or earthy. The total thickness of the Cedar Valley limestone in the county is not less than 75 feet. The rock is for the most part thin bedded, soft, and much jointed and serves as a very good water bearer.

UNDERGROUND WATERS.

SOURCES AND DISTRIBUTION.

Except at Waterloo and Cedar Falls the water supply of Black Hawk county is obtained from the Buchanan gravel, the Cedar Valley and Wapsipinicon limestones, and the Kansan drift. On the farms pumps are universally operated by windmills. Flowing wells are rare.

In the valley of Wapsipinicon river, which is confined to the eastern half of Lester township, the northeastern township of the county, the alluvial deposits are everywhere underlain by gravels, which vary somewhat in fineness and in thickness but which almost everywhere afford satisfactory supplies of good water to comparatively shallow wells. The village of Dunkerton, in sections 29 and 32, gets its water supply wholly from driven wells ending in these gravels. Norton reports two flowing wells on the slopes of the river bottom. One, the well on H. Flattendorf's place, flowed up to 1905, the other, on William McGee's place, still flows. The depth of these wells is not known.

On the Iowan drift plain lying between the Wapsipinicon valley and Cedar river valley in the north tier of townships and in general in all that part of the county east of the Cedar river valley a few wells end in sand or gravel beds or streaks within the Kansan drift, but by far the greater number end a short distance within the underlying Cedar Valley limestone. The wells range in depth from 85 to 300 feet.

A well on Clubine's place, 2½ miles north of Dunkerton, on high ground near the edge of the Wapsipinicon river bottom, is 274 feet deep and ends in sand. In a well in section 21 rock was reached at 140 feet.

Near the Bartlett quarry in East Waterloo township, on the bluffs just back from the river bottom, where the thickness of the limestone is unusually variable, wells are about 100 feet deep, the depth in rock ranging from 60 to 90 feet. Water is found just below the blue limestone.

On a small creek called Rock Run, 2½ miles east and 1½ miles north of Waterloo, two flowing wells, 109 and 87 feet deep, are reported by Mr. Purington, a pump dealer of Waterloo. Both end in coarse gravel without reaching rock.

In the immediate neighborhood of the flowing wells northeast of Waterloo are several springs. Probably springs and wells have a common source in the Cedar Valley limestone.

In Fox and Spring Creek townships, rock outcrops along the slopes of Spring creek valley up to the prairie level in many places, making it necessary for the farmers to drill all their wells.

On the wide river bottom of the Cedar most of the wells are driven, are about 18 feet deep, and end in the Buchanan gravel. The depth of the wells depends on the surface elevation, the water being found at about the level of the water in the river. Some wells on the river bottom must penetrate the blue limestone before obtaining an adequate supply of water.

At Westfield, in section 22, West Waterloo township, a 15-inch well gives the following section:

Section of well at Westfield.

	Thickness	Depth
	Feet	Feet
Sand	14	14
Gravel (Buchanan)	½	14½
Clay, light blue	18	32½
Broken rock	7	39½
Limestone, porous (first vein, water not abundant)	9	48½
Limestone, firm (second vein)	30	78½
Limestone (third vein, water abundant)	28½	107

At Washburn, Cedar township, wells 30 to 35 feet deep obtain a plentiful supply in sand. A mile and a half to the southwest is a well 60 feet deep, 12 feet in rock, and another 60 feet deep near by goes 30 feet into rock. Some wells in this vicinity are 100 feet deep. The water of these deeper wells is reported as disagreeable to the taste.

On Mr. Marble's place, half a mile east of the packing house at Waterloo, the well is 44 feet deep, 30 feet being in a very hard, compact limestone that is unusual in this county. The water rises within 14 feet of the surface.

The city well at La Porte obtains its supply from the Buchanan gravel, not entering rock. As La Porte is 812 feet above sea level (Chicago, Rock Island & Pacific Railway track elevation), an artesian well 1,400 feet or 1,500 feet deep should yield water that will rise 10 to 20 feet above the surface. The Maquoketa shale will be reached at a depth of about 300 feet, the Galena dolomite at 550 feet, the Saint Peter sandstone at 930 feet, and the Jordan sandstone at 1,300 feet. Such a well should be sunk to the bottom of the Jordan, which is about 1,450 feet below the surface.

The area southwest of Cedar river is a typical Iowan drift plain, crossed diagonally by the shallow valley of Black Hawk creek. Limestone outcrops in the immediate neighborhood of Cedar Falls, Waterloo, and La Porte, and in a limestone ridge in section 24, Eagle township. Everywhere else the rock is deeply buried beneath the drift materials.

Wells in this area range in depth from 60 to 250 feet. A few derive their supply from sand or gravel beds within the drift, but most enter the rock from 2 to 12 feet, and exceptionally penetrate rock to a depth of 20 to 60 feet. In the southwest half of this area, making due allowance for differences of surface level, the underlying rock surface is fairly uniform, but in the northeast half it varies much more. Most of the water is reported as good, but one well driller, whose experience is mainly in the southwest half, reports considerable diversity in its quality.

In Waterloo township, in the west half of section 22, at the old Hummel place, 60 feet of quicksand was passed through below 100 feet of clay. Water was obtained, but the supply did not prove permanent.

In Orange township, at the county farm (NE. 1/4 sec. 3), where the surface elevation is about 100 feet above the river bottom, the well is 175 feet deep, 110 feet being in clay and 65 feet in limestone, where the second vein yields water plentifully. A well near by is 139 feet deep, 100 feet of which is in limestone. One mile west of the county farm, on N. Miller's place, at about the same surface level, the well is 115 feet deep, 10 feet being in rock. All these wells yield unfailing supplies.

CITY AND VILLAGE SUPPLIES.

Cedar Falls.[1]—The city supply of Cedar Falls (population, 5,012) is from springs in the valley of Dry Run in sec. 13, T. 89 N., R. 14 W., a mile southeast of the postoffice. The springs issue from a fissure in the Cedar Valley limestone just above the level of the bed of Dry Run at the base of bluffs about 30

[1]By R. B. Dole.

feet high, and they furnish, with several other sources in this immediate vicinity, a total discharge estimated at nearly 6,000 gallons a minute. It is reported that the supply is somewhat less during dry weather and that the water is turbid at times of heavy rains or high river floods. The public supply is used for domestic purposes and for steam boilers, the average daily consumption being 350,000 gallons. More than two-thirds of the populaton, including the Iowa State Teachers College, is supplied with this water.

A sudden epidemic of typhoid fever occurred in the city in the fall of 1911, during which more than 100 persons were afflicted and nearly 20 died. It was the opinion of three independent investigators that the city water supply had become infected and was the cause of the epidemic. The limestone from which the water issues is exposed in the beds of Cedar river and of Dry Run and is covered throughout a greater part of the city by a mantle of coarse gravel only 5 to 15 feet thick. Many cesspools and wells enter the limestone and thus afford opportunity for contamination, as the rock is broken and full of crevices and water channels that allow free circulation of water without filtration. It is currently reported that cracks or sink holes in the be dof Dry Run above the springs have been filled up at different times in an attempt to prevent the entrance of surface water. It is evident that several possible sources of contamination of this aquifer exist in the immediate vicinity.

[1]After careful consideration of the reports and recommendations of State and Federal experts the city officials had an experimental well sunk at the pumping station. This well passes through 38 feet of alluvium, sand and gravel, then through 78 feet of limestone, heavy bedded for the most part, though the lower 14 feet is shaly. At a depth of 116 feet there was encountered a copious supply of water, which rose within 11 feet of the well mouth. A galvanized iron cylinder was inserted through the alluvial filling well into the rock. Within this cylinder an 8-inch casing was inserted within 14 feet of the bottom of the well, or to the shaly limestone which is the aquifer. By a careful test sustained for 24, 36 and 48 hour periods water was

[1]The following paragraphs were written by Professor Arey in 1912.

pumped at the rate of 500 and 600 gallons per minute without lowering its level except for four feet at the starting of the pumps. At the time of high water in the spring when spring water taken at the station was turbid, the water of the well remained clear and analysis at that time showed the water to be free from pathogenic and chemical impurities.

As a result of this experiment, two similar wells were sunk, No. 2 at a distance of 20 feet from No. 1, and No. 3 at a distance of 40 feet from No. 2.

The city is installing a new cross compound Corliss Prescott pumping engine with a capacity of 2,000,000 gallons daily, against a pressure of 90 pounds per square inch. The wells are so connected with the main suction pipe that any one or more of the wells can be used at any one time.

Every precaution has been taken to provide against a possibility of contamination of the water supply, even to the extent of infusing the standard amount of hypochlorite of lime into the water at all times, thus insuring the destruction of any pathogenic bacteria that might appear, though the water never has shown any trace of turbidity or other indications of contamination. It is believed that the problem of a safe water supply has been successfully solved, since the possibilities of contamination which existed under the former system—at the spring reservoir, through the long wooden conduit, which ran beneath the surface of the ground in a sandy bed, and at the supply well, or cistern, at the waterworks end of the conduit—have been eliminated. It has practically been proven that the contamination of the spring water has taken place by one or more of these means. Repeated and long continued tests with fluorescein have failed to show connection of the waters of Dry Run with the spring water.

Waterloo.—The city of Waterloo (population, 26,693) obtains its supply from three deep wells, respectively 1,373 feet, 1,377 feet and 1,365 feet in depth. (See Pls. VI, VII.) Previous to the drilling of these wells the water supply had been drawn from Cedar river and treated by mechanical filtration. In 1903 and 1904 a severe epidemic of typhoid fever was traced to the contamination of the water supply by sewage from a town situated up the valley, filtration having failed to destroy the microorganisms of the disease. The city officials then asked the United States Geological Survey and the Iowa Geological Survey for information as to other possible sources of supply, and W. H. Norton was detailed to make an investigation. In his report[1] a hypothetical geologic section at Waterloo was given, which is reproduced here with a parallel column showing actual depths at which the formations were encountered by the drill.

Hypothetical and actual geologic section at Waterloo.

	Estimated Thickness	Estimated Depth	Actual Depth
	Feet	Feet	Feet
Limestone and shale (Devonian)	125	125	158
Limestone (Silurian)	135	260	265
Shale (Maquoketa)	165	425	480
Limestone (Galena and Platteville)	410	835	815
Sandstone (Saint Peter) (50 to 100 feet)	80	915	862
Shakopee, New Richmond, and Oneota	400	1,315	1,205
Sandstone (Jordan)	100	1,415	(?) 1,362

The report stated that an experimental well, 1,400 feet deep, would test the capacities of the chief zones of flow, and the city officials were advised to carry the experimental boring as much farther as necessary to test the capacity of the Dresbach and underlying Cambrian sandstones. The head was estimated at between 20 and 30 feet and the discharge from a six inch well at between 100 and 300 gallons per minute. The Waterloo Water Company had such confidence in the artesian resources available that, instead of sinking an experimental well of small diameter, an eight-inch well was put down to a depth of nearly 1,400 feet. As the capacity was found to be 290 gallons under natural flow and 700 gallons under the pump, it was decided to carry the drilling no deeper to explore the Dresbach and underlying sandstones, but to drill at once a second well of about the same dimensions. The two wells together yield under the pump, 1,550 gallons per minute.

Detailed information concerning these wells follows:

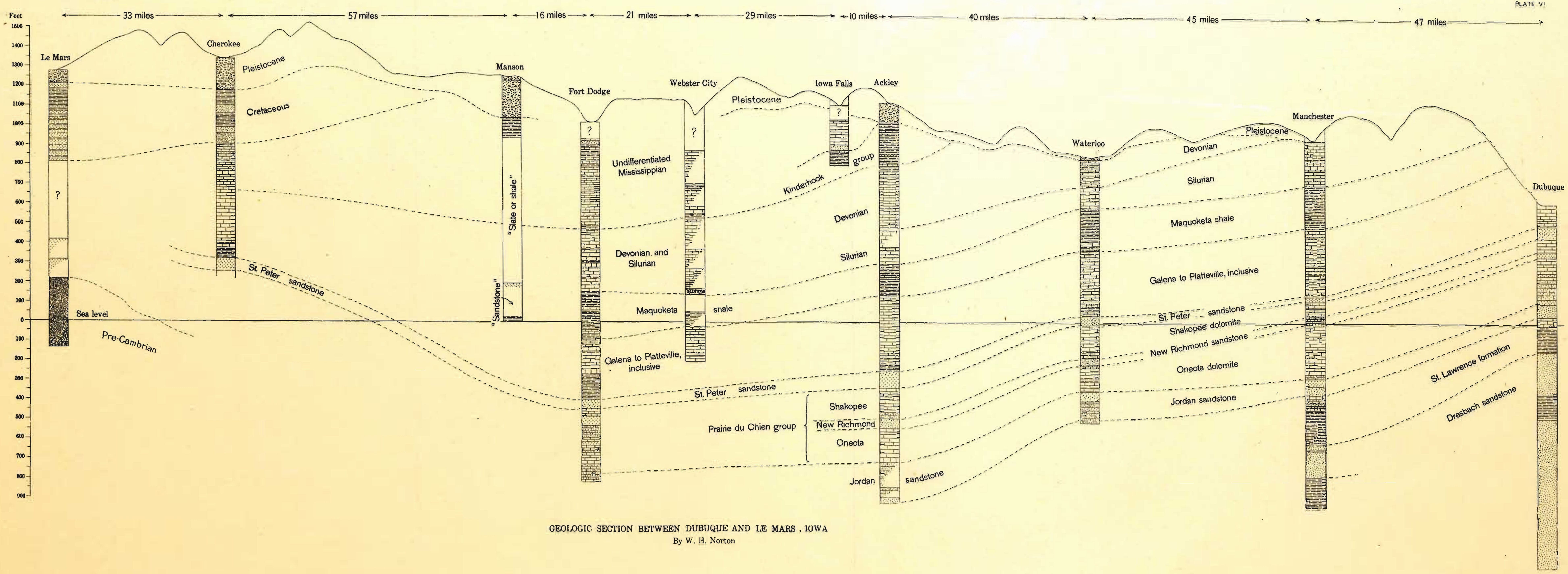
Well No. 1 has a depth of 1,373 feet and a diameter of 20 inches at top, 8 inches at bottom; casing, 35 feet of 20 inch, 106 feet of 15 inch, 284 feet of 9 inch, and 122 feet of 7 inch, making

[1]Contributions to the hydrology of the eastern United States: Water Supply Paper U. S. Geol. Survey No. 145, 1905, pp. 148-155.

a total of 547 feet from the surface. The curb is 847 feet above sea level and the head 20 feet above curb. The well flows 290 gallons per minute; its tested capacity is 700 gallons per minute. The water first overflowed from a depth of 840 fet, and very slightly increased between this and next strong flow at 1,360 feet. Temperature in August, at well mouth, 56° F. The well was completed in 1905 at a cost of about $6,000 by W. H. Gray & Brother, of Chicago.

Record of strata in Waterloo Water Company's well No. 1 (Pls. VI, VII).

	Thickness	Depth
	Feet	Feet
Quaternary (30 feet thick; top 847 feet above sea level):		
Surface deposits; no samples	30	30
Devonian (128 feet thick; top 817 feet above sea level:		
No samples	70	100
Limestone, light brown, hard, very fine-grained; rapid effervescence, some chips brecciated, fragments brown, matrix yellow, facies of Wapsipinicon limestone, considerable sand, and yellow limestone from above	5	105
Limestone, blue-gray, rough, vesicular, and drab, hard, dense; both of rapid effervescence	7	112
Limestone, buff, porous, mottled, rapid effervescence	14	126
Chert, gray and black, and limestone, yellow; rapid effervescence; some gray sandstone of fine rounded grains at 136 feet; 2 samples	17	143
Limestone, light gray; slow effervescence; soft, with dark flint and sandstone as above; residue of limestone chips, highly argillaceous, with particles of translucent gray flint, rounded grains of fine quartz sand and grains of pyrite; 2 samples	15	158
Silurian (107 feet thick; 689 feet above sea level):		
Niagaran dolomite—		
Dolomite, blue-gray, hard, porous, pure, crystalline; in small chips	12	170
Dolomite, as above, with shale, light blue-gray, calcareous	6	176
Dolomite, blue-gray, crystalline; some shale and some fragments of mottled sandstone from above	10	186
Dolomite, blue-gray	14	200
Dolomite, light blue-gray, rough, siliceous, vesicular; with cavities lined or filled with crystalline quartz	5	205
Dolomite, in fine meal, light yellow, almost white, highly argillaceous residue shows much cryptocrystalline quartz in flakes and some particles of crystalline quartz	5	210
Dolomite, blue-gray, rough, crystalline, siliceous, and cherty; 2 samples	20	230
Dolomite, light yellow-gray, finely saccharoidal; 2 samples	10	240
Dolomite, gray; in sand	5	245
Dolomite, light yellow-gray, argillaceous, and siliceous; minute grains and particles of quartz; 3 samples	20	265
Ordovician:		
Maquoketa shale (215 feet thick; top, 582 feet above sea level)—		
Shale, greenish blue and drab; in concreted masses; calcareous; at 4?5 traces of buff dolomite; 21 samples	165	430
Dolomite, crystalline, buff and brownish gray; in chips and sand; 3 samples	35	465
Shale, drab, concreted powder, calcareous; 2 samples	15	480
Galena limestone to Platteville limestone (365 feet thick; top, 367 feet above sea level)—		
No samples	15	495
Limestone, light yellow-gray; thin flakes, earthy; rapid effervescence	15	510
Limestone, argillaceous, rapid effervescence; in white powder; 6 samples	95	605
Limestone, soft, buff, and chert, yellow; drillings chiefly chert	11	616
Limestone, light gray; rapid effervescence; argillaceous; 7 samples	149	765
Shale, light green-gray, highly calcareous (probably Decorah shale)	20	785
Limestone, soft, brownish and gray	30	815
Saint Peter sandstone (47 feet thick; top, 32 feet above sea level)—		
Sandstone, white, rounded grains	47	862



GEOLOGIC SECTION BETWEEN DUBUQUE AND LE MARS, IOWA

By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON, D. C.

Report of strata in Waterloo Water Company's well No. 1—Continued

	Thickness	Depth
	Feet	Feet
Prairie du Chien stage—		
Shakopee dolomite (168 feet thick; top, 15 feet below sea level)—		
No sample	11	873
Dolomite, gray and white, hard, crystalline, in chips; much clear quartz sand, largest grains 0.8 millimeter in diameter	17	890
Dolomite, pink, vesicular, considerable quartz sand in drillings	10	900
Dolomite, gray; with much quartz sand in drillings but no grains found embedded in dolomite	63	963
Dolomite; buff, cherty, almost free from quartz sand	17	980
Dolomite, gray; in chips; sparingly arenaceous	30	1,010
Dolomite, gray; in fine chips with some quartz sand	20	1,030
New Richmond sandstone (30 feet thick; top, 183 feet below sea level)		
Sandstone, white; well rounded grains; largest grains 1.5 millimeters in diameter	15	1,045
Dolomite and sandstone, gray; much quartz sand in fine rounded grains	15	1,060
Oneota dolomite (145 feet thick; top, 213 feet below sea level)—		
Dolomite, gray and blue; cherty in places; 4 samples	65	1,125
Marl, in light yellow-gray powder; very large residue of minute particles of quartz	25	1,150
Dolomite, light buff; some white chert	20	1,170
Marl, in finest yellow-gray meal; very large residue of minute particles of chert	15	1,185
Dolomite, yellow-gray, highly cherty	20	1,205
Cambrian:		
Jordan sandstone (157 feet thick; top, 358 feet below sea level)—		
Sandstone, yellow-gray; grains rounded; largest 0.5 millimeter in diameter; in loose sand and in small chips of buff calciferous sandstone	15	1,220
Sandstone, gray; largest grains about 1.5 millimeters; in loose sand, with some chips of soft, very fine-grained bluish sandstone	15	1,235
Sandstone, gray; clean rolled grains, largest 1 millimeter in diameter	18	1,253
Dolomite, highly arenaceous; in small chips and sand of fine rolled grains	17	1,270
Dolomite, minutely arenaceous; in fine light yellow-gray powder; large residue of minute quartz particles	10	1,280
Dolomite, yellow-gray, minutely arenaceous; with considerable fine quartz sand in drillings	22	1,302
Dolomite, light gray, crystalline, vesicular, arenaceous; in chips	60	1,362
Saint Lawrence formation (11 feet penetrated)—		
Dolomite, yellow-gray	11	1,373

The Waterloo Water Company's well No. 2 is located about 1,600 feet from well No. 1. It has a depth of 1,377 feet and a diameter of 20 inches to about 201 feet, 10½ inches to 626 feet, and 8¼ inches to bottom; 20-inch casing to 139 feet 4 inches, 16-inch to 201 feet 2 inches, and 9-inch to 626 feet;hemp packing at 198 feet. The curb is about 847 feet above sea level and the head, 4 feet 5 inches below the curb. The tested capacity is 850 gallons per minute, temperature, 54° F. The well was completed in 1907 by W. H. Gray & Brother, of Chicago.

The Waterloo Water Company's well No. 3, recently drilled, has a depth of 1,365 feet and a diameter of 20 inches to 200 feet and of 12 inches to bottom; casing, 200 feet of 20-inch and 660 feet of 12-inch, casing off the Saint Peter. Temperature, 54° F. The well cost $11,000. It was drilled by the Whitney Well Company, of Chicago, in 1911.

BREMER COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

Topographically Bremer county is part of the wide Iowan drift plain of northeastern Iowa. Cedar, Wapsipinicon, and Shell Rock rivers cross it in three wide valleys cut 60 to 80 feet below the adjacent prairie levels. The broad alluvial floor of the Cedar is in places two and even three miles wide and is incised below its ancient gravelly flood plains, but the Wapsipinicon, whose valley is 1½ to two miles wide, still flows well up to the level of the glacial outwash of its aggraded floor.

About Waverly and near Denver small insular areas of high loess-capped hills of Kansan drift, separated by intricate and deep ravines, overlook the Iowan drift plain.

GEOLOGY.

Nearly the whole of Bremer county is underlain by rocks of the Devonian system. Owing to local deformation the Niagaran dolomite (Silurian) comes to the surface in two or three isolated areas. An ancient wide, rock-cut valley, now completely filled with drift, extends from north to south between the valleys of the Wapsipinicon and the Cedar, and in it the drill discovers beneath the drift the blue Maquoketa shale (Ordovician).

UNDERGROUND WATER.

SOURCES.

The ground-water beds of the county consist of alluvial sands and gravels on the flood plains of the rivers, sands at the base of the loess, lenses of sand included within the drift sheets, beds of sand and gravel parting the Iowan and Kansan drift sheets and separating the Kansan from the still earlier Nebraskan drift beneath it, sand resting on bedrock, broken layers of rock immediately underlying the drift, and indeterminate beds within the Devonian limestones.

DISTRIBUTION.

The lateral extent of the beds just named may be briefly stated. Alluvial sands and gravels are restricted to the valley floors of the arger streams. As a rule they furnish plentiful supplies for stock and house wells, except on well-drained terraces which are remnants of ancient flood plains, now left some distance above the present stream by the downcutting of the channel. The towns of Plainfield and Horton in the valey of Cedar river are thus supplied.

Loess is restricted to an area extending southeast from Waverly to Denver, and in the northwestern part of this area is limited to isolated hills and groups of hills rising from the Iowan drift plain. In the southeastern part of the area it forms a continuous and heavy sheet mantling a deeply eroded upland of Kansan drift. This porous deposit acts as a sponge, absorbing water during rains and discharging it somewhat freely, both by evaporation and downward percolation in dry weather. But the supplies drawn from its basal silts and sands have not as a rule been found to be either permanent or large. Moreover, where the loess is thickest and most extensive it rests directly on clays of Kansan age with no intermediary gravels to furnish a reservoir. Even here, however, seepage wells that furnish sufficient water for house use or for small farms not carrying much stock can be had in favorable situations from the somewhat more porous silts at the base of the loess.

The loess passes downward into a yellow water-bearing sand about the margins of the Iowan drift plain and along the bases of the isolated hills about Waverly, but here there is no great extent of loess to act as an intake area, so that the supply must be small.

The several beds of sand and gravel associated with the drift occur throughout the county and form reliable and much-used water beds. The Devonian is also nearly as extensive as the county. Where the drift is thick drillers report that in many localities water is found in the shattered surface rock broken in part by preglacial weathering. As the Devonian limestones are easily soluble well-opened waterways have been dissolved out along joints and bedding planes and in places connected with the surface by sinkholes. Over a considerable area, where these limestones have been cut away by preglacial river erosion, wells depend entirely on water-bearing beds in the drift.

UNDERGROUND-WATER PROVINCES.

Wapsipinicon Valley.—The valley of Wapsipinicon river from Frederika south to the county line is a plain 1½ to more than two miles wide, cut about 60 feet below the level of the adjacent prairie. (See fig. 3.) The ill-drained valley floor descends from the bases of the gentle slopes of the bordering hills by almost imperceptible degrees to the little river. From 10 to 20 feet of alluvial sands cover the surface, beneath which the drill finds, from Tripoli south, a stony clay 50 to 80 feet thick, the deposit of an ancient ice sheet, probably the Kansan. Underlying these impermeable beds lie water-bearing sands and gravels of unknown thickness, laid apparently on the floor of a preglacial or interglacial valley cut either in bedrock or in an older drift. As this water bed rises up the valley with the gradient and also on the valley sides, where no doubt it connects with glacial sands on the adjoining uplands, and as it is covered by heavy clays, the water it contains is under artesian pressure and wherever tapped gives rise to flowing wells. The same conditions obtain in the lower part of the valley of the East Wapsipinicon.

Although farmsteads are few on these valley floors, which, owing to their ill-drained condition, are used chiefly for pasture and grass land, and although the rivers themselves furnish a supply for stock, yet nearly all the farmsteads in the valley and several located some distance up the valley sides have obtained copious flows of palatable and pure artesian water.

The pioneer wells of this field were sunk more than 30 years ago, and the head of a number has diminished. The static level of some wells on the hill slopes has been so drawn down that they have ceased to flow, but the supply is still ample on all the bottom lands. It is usually wisely economized by discharge pipes not more than three-fourths of an inch in diameter. Some wells are plugged during the portion of the day when they are not in use.

The reported head varies considerably. The highest given is that of the J. J. Cook well, in the SE. ¼ sec. 1, T. 92 N., R. 12 W., in which the water rose to a height of 21 feet above the curb as measured in a pipe. This well is situated at the base of the bordering hill slopes, and the curb is several feet higher than that of the other wells situated well out upon the valley floor. Among the latter, that of Christian Baker had a head of 30 feet; others are said to have heads as low as 10 feet.

It is reported that the head of wells on the upland between Wapsipinicon river and Buck creek has distinctly lowered, in some wells as much as 10 feet, and this decrease has been attributed to the flowing wells of the adjacent valley.

The midsummer temperature of the wells flowing under greatest pressure, and hence least warmed in their pipes, is about 47° F.

Up the valley from Tripoli water rises nearly to the surface but does not overflow. The only well near Tripoli of which a section has been obtained shows alluvial sand and stony clay to 60 feet, underlain by four feet of sand from which water rises within five feet of the surface. Another well, 2¾ miles to the north, in the NW. ¼ sec. 18, T. 93 N., R. 12 W., found no blue stony clay but passed directly from 10 feet of yellow clay into gravel which became more and more coarse, till at 53 feet, the bottom of the well, its pebbles were larger than hen's eggs.

Buried channel of "Bremer River."—A ground-water province of special interest is defined by a deep preglacial buried valley which traverses the county from northwest to southeast through Douglas, Warren, Jefferson, and Maxfield townships (see fig. 3.) Here numerous wells, from 200 to 273 feet deep,

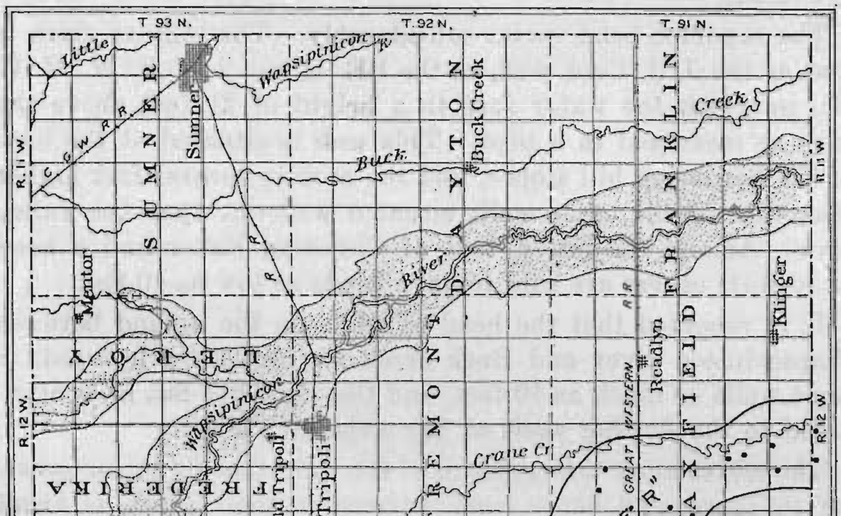


Figure 3.—Map of artesian field of Wapsipinicon river and of buried channel of Bremer river.

end in drift, thus failing to reach the rock floor of the ancient valley. The depth in rock to which the valley was cut is at least 220 feet, as shown by the elevation of outcrops 2½ miles distant. In the southern part of the county the ancient fluvial floor lies at least 160 feet below the rock bed of Cedar river at Waverly, or at an elevation less than 765 feet above sea level.

The drift is heavy on both sides of this buried valley and particularly so on the east side, where few wells reaching rock are reported. The facts at hand warrant the belief that the valley is at least as wide as that of the Upper Iowa in Allamakee county, this stream being selected for comparison because it is a preglacial Iowa valley in the driftless area. The spacing of the deeper wells demands a width of at least 1½ miles, and no data are at hand which negative an estimate of twice that width. Wells, by no means the deepest of the area, which enter rock encounter either the dry shales of the Maquoketa or a thin bed of Niagaran dolomite. Beyond doubt at least the medium portion of the channel was cut in the Maquoketa shale, and in this weak rock a wide valley is to be expected.

As the valley floor is made for the most part of dry shale, wells which fail to find water in the drift are compelled to go to an exceptionally great depth to the limestones of the middle part of the Maquoketa or even to those of the Galena and Platteville. The large majority of wells in this "deep country," as drillers term it, find water in the sand and gravel associated with the drift.

In Douglas township the few wells reported which are referable to the channel find little or no sand so far as known, the channel here apparently being filled with blue stony clay. Two wells were compelled to go deep into rock for water, one in section 27 to 337 feet and one in section 6 to 266 feet. Both wells passed through the upper shale of the Maquoketa and found water in limestones referred to the Middle Maquoketa, the shale in the first well being 87 feet thick overlain with 10 feet of Niagaran dolomite, and in the second 60 feet thick overlain with drift.

In at least the northern part of Warren township no continuous and heavy bed of sand is found in the channel, although a number of wells find water-bearing sands and gravels in the drift amply sufficient for farm supply. Thus in section 5 three wells find water-bearing sand at depths of 236, 150 and 92 feet, and in section 4 a well entering rock at 180 feet was compelled to go 287 feet before obtaining a supply. In section 17 a well which enters the Niagaran at 212 feet passes through 100 feet of shale (Upper Maquoketa) before finding water at its base at 317 feet below the surface, no gravels or sands being here reported from the drift.

Where the channel crosses the northeast corner of Jefferson township, wells find the stony clays of the Kansan (together with those perhaps of the Nebraskan) more than 200 feet in thickness. Here a water bed of sand and gravel is entered at about 200 feet and in one well was penetrated to a depth of 15 feet.

In Maxfield township the channel seems to reach its greatest depth. Along its course none of the deeper wells reach rock. The drill here passes through from 230 to 260 feet of yellow and blue clay before reaching water-bearing gravels whose depth is quite unknown. In some of these wells water rises to within 50 feet of the surface.

A little outside of the channel, in section 8 of Maxfield township, two wells failed entirely to find water sands either in or beneath the drift, which here consisted of stony clays 190 and 170 feet thick. In the first well the drill entered limestone (Niagaran), three feet thick, immediately below the drift, and thence passed through 300 feet of shale, the entire Maquoketa. Entering then the Galena limestone it was necessary before finding water to penetrate 191 feet, making the total depth of the well 684 feet. In the second well on this section the drill passed through 285 feet of the Maquoketa shale and penetrated the Galena limestone 10 feet, the well being unfinished at date of writing.

The buried channel of "Bremer River" thus seems to differ from many similar "deep countries" in the absence of thick, continuous, and hence reliable water-bearing sands. The sinking of a well in this belt is therefore as much of an experiment as anywhere else in Iowa. The drill may strike water in one of the scattered lenses of sand within 100 feet or may be compelled to go 200 feet and more to the main water-bearing sand. Even this may fail, and the drilling, if continued, must be carried at least to the limestones of the Middle Maquoketa and possibly even deep into the Galena. Fortunately wells are uncommon in which water is not found in gravels within at least 270 feet of the surface.

CITY AND VILLAGE SUPPLIES.

Denver.—Waterworks at Denver (population, 224) were built in 1907 with supply from a well 132 feet deep. The log of the well is as follows:

Log of city well at Denver.

	Thickness	Depth
	Feet	Feet
Clay, yellow	18	18
Clay, blue	70	88
Quarry rock to water	28	116

Water is pumped to an elevated tank and thence distributed through 1,200 feet of mains. There are three fire hydrants. The house supplies are still obtained from wells which differ greatly in depth to rock and in depth at which water is found in rock. The drift gravels may or may not furnish an adequate supply. A buried channel, connecting with that of Bremer River, which runs a few miles east of the town, has largely cut away the Devonian and Silurian limestones, and wells in places may pass from the drift into dry Maquoketa shale. The following wells illustrate the various conditions:

Log of Clausing's well, one block from Main street.

	Thickness	Depth
	Feet	Feet
Drift	66	66
Gravel and sand	10	76
Drift	86	162
Shale, blue (Maquoketa)	248	410

The Clausing well was a failure, but another well sunk on the same lot secured water in gravel at 90 feet.

Log of well on Main street, a block from Clausing's well.

	Thickness	Depth
	Feet	Feet
Clay, yellow	12	12
Clay, blue, pebbly	30	42

Log of Henry Bauman's well three blocks east of Clausing's well.

	Thickness	Depth
	Feet	Feet
Drift	120	120
Limestone	4	124
Shale, red, soft	8	132
Shale, blue	88	220

This well was a failure, but, the drill being moved 16 feet away, a successful well was secured with the following log:

Log of second Bauman well.

	Thickness	Depth
	Feet	Feet
Drift	120	120
Limestone (water bearing)	40	160

Frederika.—Frederika (population, 149) is situated on a rock bench covered with a veneer of alluvial sand and gravel 10 to 20 feet thick. Wells obtain water from the Devonian limestones at a depth of from 35 to 45 feet from the surface.

A hole drilled for the Pioneer Oil Company in 1903, by L. Wilson & Company of Chicago, Illinois, was carried to a depth of 1,025 feet. The surface elevation at the hole is about 1,050 feet above sea level.

The strata penetrated are shown by the following section, based on the driller's log:

Record of starta in deep drill hole at Frederika.

	Thickness	Depth
	Feet	Feet
Pleistocene	38	38
Devonian and Silurian (112 feet thick; top, 1,012 feet above sea level):		
Shale, blue	14	52
Shale, yellow	20	72
Limestone, blue	31	103
Shale, yellow	47	150
Ordovician:		
Maquoketa shale (166 feet thick; top, 900 feet above sea level)—		
Shale, blue	85	235
Limestone	65	300
Shale, blue	16	316
Galena limestone to Platteville limestone (349 feet thick; top, 734 feet above sea level)—		
Limestone, brown	51	367
Limestone, white	23	390
Limestone, dark gray	90	480
Limestone	97	577
Shale	23	600
Limestone	25	625
Shale, blue	32	657
Gumbo	8	665
Ordovician—Continued.		
Saint Peter sandstone (52 feet thick; top, 385 feet above sea level)—		
Sandstone	52	717
Prairie du Chien stage (308 feet thick; top, 333 feet above sea level)—		
Limestone, brown (Shakopee)	121	838
Sandstone (New Richmond)	45	883
No record	142	1,025
Limestone, brown (Oneota)		1,025

Plainfield.—Open and driven wells supply Plainfield (population, 288), which is situated on the terraces of the flood plain of Cedar river.

Readlyn.—At Readlyn (population, 227), wells drilled to a depth of 80 to 125 feet enter rock at about 80 feet. Drillers report the following succession of deposits:

Log of wells near Readlyn.

	Thickness	Depth
	Feet	Feet
Clay, yellow	60	60
Clay, blue	10	70
Clay, yellow, to rock	10	80

Sumner.—The town of Sumner (population, 1,404) is supplied by an artesian well 1,770 feet deep, drilled by J. P. Miller & Company, of Chicago, in 1902. The well is 10 inches in diameter to 120 feet, 8 inches to 234 feet, 6 inches to bottom; casing to 730 feet. The curb is 1,054 feet above sea level and the head is 144 feet below curb. Water in the Middle Maquoketa at 260 feet rose to 18 feet below curb; the temperature of this water was 51° F. Water was also found in the Galena at 420 to 660 feet, and in the Oneota at 1,086 feet, the lower waters heading 144 feet below curb. The well yields 200 gallons per minute with pump cylinder 204 feet below curb.

The strata penetrated are indicated by the following section:

Record of strata in Sumner city well.

Pleistocene (128 feet thick; top, 1,054 above sea level):	
Sand and gravel, yellow	40
Gravel, coarse; pebbles in sample up to 3 inches diameter	41
Till, glacial, stony clay, drab; sandy at 90 feet; 7 samples	50-120
Devonian or Silurian (22 feet thick; top, 926 feet above sea level):	
Limestone, largely drab; fine-grained, of Wapsipinicon type	128
Limestone, hard, light buff; of rapid effervescence; 2 samples	135-140
Limestone and shale; limestone, light buff, of rapid effervescence; shale, drab; 2 samples	150-160
Ordovician:	
Maquoketa shale (220 feet thick; top, 904 feet above sea level)—	
Shale, blue-green, plastic, calcareous; 5 samples	170-220
"Hard rock" in driller's log at	230
Drift, sand and gravel	235
Limestone, light blue-gray; earthy luster, mottled; of rapid effervescence in cold dilute HCl, with much chert of same color; 4 samples	250-280
Limestone, soft, semicrystalline, gray; rapid effervescence; cherty; 1 sample containing crinoid stem; 3 samples	290-310
Shale, light blue-green, calcareous; 5 samples	320-360
Galena limestone to Platteville limestone (344 feet thick; top, 684 above sea level)—	
Limestone, blue-gray; of rapid effervescence; 3 samples	370-390
Shale, calcareous, drab; 2 samples	400-410
Limestone, cream colored, soft; in thin flakes	410-420
Limestone, light and dark gray; soft, earthy luster; rapid effervescence; 21 samples	430-610
Limestone, dark blue, highly fossiliferous; 2 samples	640-650
Shale, bright green, plastic, slightly calcareous; 3 samples (probably Decorah shale)	660-668
Limestone, mottled gray, fossiliferous; rapid effervescence; 5 samples	678-710
Shale, bright green; highly fossiliferous at 710 feet; fragments with bits of characteristic fossil brachiopods, etc., occur in almost all the drillings from below	710-714
Saint Peter sandstone (66 feet thick; top, 340 feet above sea level)—	
Sandstone, of clean, white, quartz sand; grains well rounded, rather fine; at 720 feet some limestone chippings in the drillings; 5 samples	720-770
Prairie du Chien stage—	
Shakopee dolomite (140 feet thick; top, 274 above sea level)—	
Dolomite, white, gray and light buff; in places cherty, crystalline; 7 samples	780-850
Dolomite, cream colored; much quartz sand in drillings	860
Dolomite, pink, arenaceous; with minute rounded grains of crystalline quartz; 2 samples	870-880
Dolomite, light buff and pinkish; 3 samples	890-910
New Richmond sandstone (40 feet thick; top, 134 feet above sea level)—	
Sandstone and dolomite; drillings chiefly fine grains of quartz sand, but with chips of light gray dolomite; 2 samples	920-930
Sandstone, fine-grained, white; grains well rounded	940
Sandstone, white, and dolomite, gray	950

Oneota dolomite (200 feet thick; top, 94 feet above sea level)—	
Dolomite, white or light gray; in places saccharoidal, in places with white chert; at 980 feet drillings contain considerable sand; 13 samples	960-1,080
Sandstone, of white clean quartz, grains well rounded; moderately fine	1,090
Dolomite, white and light gray and buff; siliceous residues of finely divided quartzose matter; at 1,150 feet finely arenaceous; 3 samples	1,120-1,150
Cambrian:	
Jordan sandstone (120 feet thick; top, 106 feet below sea level)—	
Sandstone, fine-grained, white; grains of clear quartz, well rounded; 2 samples	1,160-1,170
Sandstone, as above, but coarser, largest grains 1 millimeter in diameter	1,180
Sandstone; 3 samples	1,210
Indecisive; at 1,236 feet highly calcareous shale, resembling Maquoketa; at 1,230 and 1,240 limestone, clearly Galena or Platteville and fallen in the boring; considerable quartz sand may have fallen from above but is the only material in samples in which the drill apparently could have worked; 3 samples	1,230-1,240
Sandstone, fine, white; Galena or Platteville limestone in the drillings; 2 samples	1,260-1,270
Saint Lawrence formation (460 feet penetrated; top, 226 feet below sea level)—	
Dolomite, highly siliceous; minute angular particles of crystalline quartz; in places green grains of glauconite; 13 samples	1,280-1,425
Shale, reddish, slightly calcareous	1,430
Shale, green, slightly calcareous; 3 samples	1,440-1,460
Shale, green, fossiliferous, practically noncalcareous; minutely quartzose; 5 samples	1,480-1,520
Shale, bright and light green, highly arenaceous; minute grains of quartz; glauconiferous	1,530-1,550
Sandstone, gray, fine-grained; glauconite grains	1,560
A few water-worn fragments of shale	1,570
Chiefly rusted chips of iron, from a fallen slush bucket, cut up by the drill	1,580
Sandstone, gray, fine-grained	1,600
Shale, dark and bright green; minutely arenaceous and glauconiferous; 20 samples	1,610-1,620
Sandstone, fine-grained; some greenish argillaceous material; dried blocks set after pouring from slush bucket are readily friable	1,630
Shale, light green, finely arenaceous, slightly calcareous, plastic	1,640
Marl, green, greenish yellow, or greenish gray; highly arenaceous with almost impalpable quartz grains; calcareous and argillaceous; glauconite present in round dark green grains; some samples easily friable when dried, others more clayey and somewhat tenacious; 9 samples	1,660-1,740

The water is distributed through 2½ miles of mains to 92 taps and 14 fire hydrants under 50 pounds pressure.

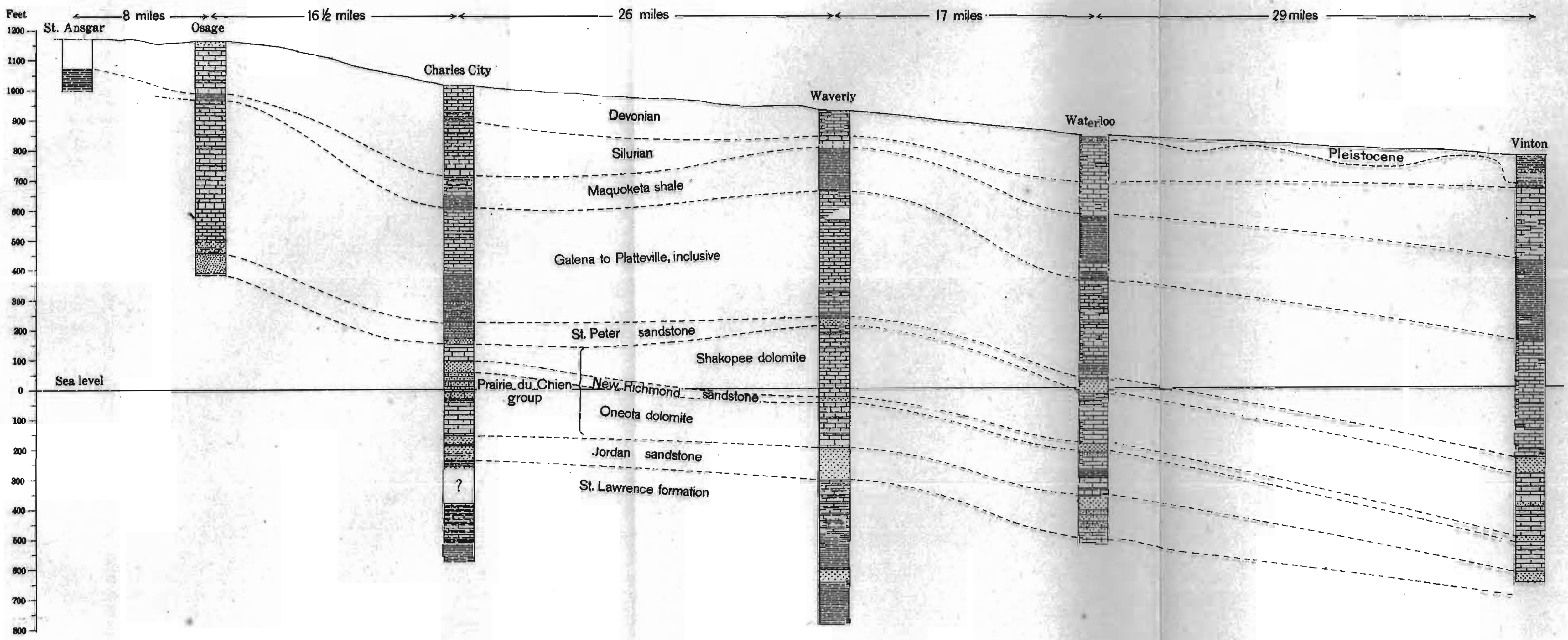
Tripoli.—The town of Tripoli (population, 755) is supplied from a well 113 feet deep, said to be capable of furnishing at least 70 barrels an hour. Water is distributed from a tank (capacity, 2,000 barrels) set on posts 90 feet high. There are 6,000 feet of mains, 16 fire hydrants, and 50 taps. Most wells in the village find water in gravel resting on bedrock.

Waverly.—The city of Waverly (population, 3,205) is supplied by an artesian well 1,720 feet deep, drilled in 1899 by J. P. Miller & Company, of Chicago. (See Pl. VII.) The well is 12 inches in diameter to a depth of 15 feet, 10 inches to 100 feet, 8 inches to bottom, and is cased to a depth of 100 feet. The curb is 930 feet above sea level. The head was not tested, but the natural flow is 225 gallons per minute. Water was found at a depth of 730 feet (in the Saint Peter), at 840 to 900 feet (in the Shakopee, first flow), and at 1,120 to 1,200 feet (in the Jordan). The temperature is 53° F.

The strata penetrated are shown by the following table:

Record of strata in city well at Waverly.

	Feet.
Devonian (70 feet thick; top, 930 feet above sea level):	
Limestone, buff, earthy	20
Limestone, light buff, earthy	30
Limestone, dense, hard, brittle, brownish drab and light buff, of finest grain and conchoidal fracture; rapidity of effervescence in cold dilute HCl indicated a very slight percentage of magnesium carbonate; facies of Wapsipinicon limestone	40
Limestone, as above, with a few chips of flint and some of light yellow arenaceous limestone	50
Limestone, light buff, earthy, rapid effervescence	60
Silurian:	
Niagaran dolomite (50 feet thick; top, 860 feet above sea level)—	
Dolomite or magnesian limestone, gray, earthy luster	70
Dolomite or magnesian limestone, in coarse chips, with flakes of bluish white subtranslucent cryptocrystalline quartz	80
Dolomite or magnesian limestone, yellow-gray; in fine sand	90
Dolomite, in large chips, gray, earthy luster, with cryptocrystalline silica	100
Dolomite or magnesian limestone, soft, blue, subcrystalline	110
Ordovician:	
Maquoketa shale (150 feet thick; top, 810 feet above sea level)—	
Shale, blue; with small nodules of pyrite and fine sand of bluish limestone chippings	120
Limestone, soft, blue, saccharoidal, of brisk effervescence, pyritiferous	130
Shale, calcareous, bluish or greenish; 13 samples	140-260
Galena limestone to Platteville limestone (420 feet thick; top, 660 feet above sea level)—	
Limestone, mottled, light and dark drab. fine saccharoidal, magnesian	270
Flint, light drab; in large chips; with blue-gray limestone, of rapid effervescence	280
Limestone, blue, gray; of rapid effervescence; soft, argillaceous, with considerable flint; 3 samples	290-320
Limestone, white, light gray and cream colored; in thin flakes; rather soft, somewhat argillaceous; luster earthy; effervescence rapid; 16 samples	360-590
Shale, green; with some fine chips of limestone	600
Limestone, soft, earthy, nonmagnesian, light gray, fossiliferous	610
Limestone and shale; the latter green; two samples for this depth, one of limestone and one of shale, may represent the interval between 610 and 630 feet	620



GEOLOGIC SECTION BETWEEN ST. ANSGAR AND VINTON, IOWA
By W. H. Norton

THE NORRIS PETERS CO., WASHINGTON

	Feet
Shale, green; in angular chips, with some chips of light gray limestone, as above	630
Limestone, soft, earthy; with much green shale; 3 samples	640-660
Shale, green, bright, plastic; large pieces of dried clay cleaned from drill; 2 samples	670-680
Saint Peter sandstone (30 feet thick; top, 240 feet above sea level)—	
Sandstone, white, soft; grains of pure quartz, moderately well rounded and rather fine; 3 samples	690-710
Prairie du Chien stage—	
Shakopee dolomite (240 feet thick; top, 210 feet above sea level)—	
Dolomite, gray, cherty; with chips of white saccharoidal sandstone and much quartz sand	720
Dolomite, hard, crystalline, light gray and cream colored; in chips with much quartz sand; 3 samples	740-780
Dolomite, light yellow-gray; in chips mingled with much white sand	790-920
(Drillings said to have washed away because of overflow at 840 feet.)	
Dolomite, white, crystalline, cherty; with much moderately fine quartz sand; 2 samples	930-940
Dolomite, cream colored	950
New Richmond sandstone (20 feet thick; top, 30 feet below sea level)—	
Sandstone, white, fine-grained, calcareous cement; in small chips, with some pink dolomite and grains of sand	960
Dolomite, light gray, cherty, arenaceous	970
Oneota dolomite (150 feet thick; top, 50 feet below sea level)—	
Dolomite; mostly in clean sand and chips, vesicular, white, gray, pink; some cherty; 13 samples	980-1,120
Cambrian:	
Jordan sandstone (110 feet thick; top, 200 feet below sea level)—	
Sandstone, white, soft; of clear quartz, grains rounded, general size of grain of last sample about 0.5 millimeter in diameter; 3 samples	1,130-1,150
Sandstone; drillings apparently consist in part of angular sand of light yellow dolomite, effervescing freely in hot HCl. Under the microscope it is seen to consist of minute angular grains of limpid crystalline quartz with calcareous cement; much of the drillings consists of rounded grains of white sand; 2 samples	1,160-1,170
Sandstone; quartz, moderately fine and well rounded, with chippings of gray dolomite	1,180
Sandstone, calciferous; 2 samples	1,190-1,200
Sandstone, fine-grained, white	1,210
Sandstone, calciferous; with some flakes of dolomite; 2 samples	1,220-1,230
Saint Lawrence formation (480 feet penetrated; top, 310 feet below sea level)—	
Dolomite, highly siliceous; with finely divided quartzose matter of angular particles, somewhat arenaceous; with bright green grains of glauconite; 4 samples	1,240-1,270
Chert and dolomite and siliceo-calcareous shale	1,280
Dolomite, highly argillaceous and siliceous	1,290
Dolomite, gray, siliceous; silica in form of minute angular crystalline particles constituting a large part of the rock; some green grains of glauconite; 5 samples	1,300-1,340
Shale, bluish green, slightly calcareous; 4 samples	1,410-1,440
Shale, pink, buff and green, noncalcareous	1,450
Shale, blue-green, somewhat indurated, noncalcareous; 8 samples	1,460-1,530
Sandstone; rather coarse grains, drillings contain clayey admixture and dolomite chips	1,540-1,580
Shale of various colors; yellow, a strong, dark green set thickly with grains of red; arenaceous, with small, partly rounded quartz grains	1,590
Shale, blue-green; with considerable red shale, probably from above; 9 samples	1,600-1,720

The water is pumped to a tank with a capacity of 60,000 gallons, and distributed through eight miles of mains to 52 hydrants and 350 taps. Domestic pressure is 70 pounds, and fire pressure 125 pounds.

The excellent artesian supply has largely displaced the house wells of the town. Wells sunk before its introduction found water at varying depths. On the river terrace of Sturtevant's addition driven wells 15 to 20 feet deep were used. On the high hills of the first ward wells were sunk through loess and drift nearly 100 feet to rock. On the east side of the river a former channel of the Cedar is sounded by wells, which on the bottom lands of the fourth ward descend between 90 and 100 feet in river sand throughout, showing that the old rock floor lies scores of feet below the present rock-cut channel of the river through the town.

Waverly Junction.—At Waverly Junction (population, 80) wells range in depth from thirty feet (driven) to 100 feet (drilled). Rock is entered at thirty to forty feet below the surface.

The following tables give data of typical wells in Bremer county:

Typical wells of Bremer county.

Owner	Location	Depth	Depth to rock	Head above or below curb	Remarks (log given in feet)
T. 93 N., R. 14 W. (Polk)					
R. P. Black	NE. ¼ SE. ¼ sec. 3	75	40	--------	
M. Carrier	SE. ¼ NE. ¼ sec. 4	139	115	124	Said to be flowing stream at bottom.
T. 93 N., R. 13 W. (Douglas)					
J. Neuendorf	NE. ¼ SE. ¼ sec. 2	200	190	--------	
J. H. Beam	NE. ¼ NW. ¼ sec. 3	200	170	--------	
C. Zwanziger	SE. ¼ SE. ¼ sec. 6	266	200	--------	Blue clay, 200; soft rock and shale (Upper Maquoketa), 60; hard limestone (Middle Maquoketa) 6.
Republic Creamery	NW. ¼ SW. ¼ sec. 9	180	178	--------	Creek bottom.
A. Biarmann	SE. ¼ SW. ¼ sec. 26	111	100	--------	
H. Winzenberg	SW. ¼ SW. ¼ sec. 27	220	49	--------	Yellow clay, 30; blue clay, 19; limestone (Niagaran), 10; shale (Upper Maquoketa), 87; "sandstone" (perhaps sharp yellow sand cut from dolomite of Middle Maquoketa), 20.

Typical wells of Bremer County—Continued

Owner	Location	Depth	Depth to rock	Head above or below curb	Remarks (log given in feet)
L. Burgman	SW. ¼ SE. ¼ sec. 17	65		—10	
D. Moler	NW. ¼ NW. ¼ sec. 35	196	170		First rock struck a soapstone (shale) at 20; then 6 of gray rock containing water.
T. 93 N., R. 12 W. (Frederika and part of Leroy).					
M. Collins	SW. ¼ sec. 5	100	80		
J. N. Johnson	SE. ¼ SW. ¼ sec. 6	53	13		
M. Mowatt	NW. ¼ NE. ¼ sec. 8	105	55		
J. Pinkerton	NE. ¼ NE. ¼ sec. 8	72	52		
W. J. Meier	SE. ¼ NE. ¼ sec. 8	100	92		
M. O. Connell	NW. ¼ NE. ¼ sec. 9	80	60		
F. Wolfgramm	NW. ¼ NW. ¼ sec. 16	97	91		
C. L. Rima	SE. ¼ SW. ¼ sec. 18	53	13		
F. Schultz	SE. ¼ NE. ¼ sec. 31	103			Yellow clay, 12; blue clay, 86; sand, 5; ends in sand.
C. F. Schwem	NW. ¼ NW. ¼ sec. 32	87	60		Yellow clay, 10; blue clay, 24; sand, 16; blue clay, 10; rock, 27.
C. E. Falcher	NW. ¼ NE. ¼ sec. 22	146	136		Upland. Yellow clay, 12; blue clay, 63; old ill-smelling soil, 20; blue clay, 41; rock, 10.
H. J. Pelton	NW. ¼ SE. ¼ sec 1	190		—60	Upland. Yellow and blue clay; struck 25 feet of soft jumping clay, 156; water-bearing sand to bottom.
F. McConnell	NW. ¼ NE. ¼ sec. 3	73		—10	Close to East Wapsipinicon bottoms.
J. Leach	NE. ¼ NE. ¼ sec. 3	112		—40	All clay to water-bearing gravel at bottom.
F. H. Friedman	3 miles NE. Tripoli	230		+2	Ends in water-bearing sand; yields 10 gallons per minute.
John McQueeny	NW. ¼ NE. ¼ sec. 18	283	200	—50	Divide. Drift, 200; shale (Upper Maquoketa), 60; lime rock (Middle Maquoketa), 23.
A. Schmidt	NE.¼ NW.¼ sec. 18	222	220		Divide. Drift clays, 135; quicksand (fine dark gray), 60; blue clay, 25; soft shale (Maquoketa), z.
W. B. Barnes	NW.¼ NW.¼ sec. 18	158		+4	Near foot of hill by Mentor creek. Blue clay, 96; quicksand and wood, 60; coarse gravel and water, 2.
E. Webster	NE. ¼ sec. 19	49			Water in gravel.
T. 93 N., R. 11 W. (Sumner and part of Leroy).					
P. O'Connell	NW. ¼ NE. ¼ sec. 8	310	170	—80	High prairie. Yellow clay, 15; blue clay, 155; limestone, 140.
Creamery	SE. ¼ SE. ¼ sec. 5	128	116		
J. M. Jenks	SE. ¼ SE. ¼ sec. 9	153	147		
F. C. Krause	NE. ¼ NE. ¼ sec. 10	195	194		Blue clay, 194; limestone spalls, 1.
C. Shophouster	SW. ¼ SW. ¼ sec. 14	141	136		All clay to rock.
J. M. Jenks	NW. ¼ NW. ¼ sec. 15	120			Ends in 6 feet of sand.
H. Friend	SE. ¼ NE. ¼ sec. 17	116	112		
G. Hammetter	SW. ¼ sec. 21	138			Blue clay, 132; sand, 6.

Typical wells in Bremer County—Continued

Owner	Location	Depth	Depth to rock	Head above or below curb	Remarks (log given in feet)
T. 92 N., R. 14 W. (Lafayette and part of Washington).					
W. S. Grover	SE. ¼ NE. ¼ sec. 3	130	100		
W. Blasier	SW. ¼ NE. ¼ sec. 4	(?)	29		Bottoms of Cedar river.
H. S. Bunth	NE. ¼ NE. ¼ sec. 10	(?)	130		Upland.
C. A. Kingsley	NW. ¼ sec. 17	80	80		Yellow clay, 15; blue clay, 65; white limestone.
W. M. Colton	SE. ¼ NE. ¼ sec. 20	102	30		On upland. Drift, 30; limestone, 25; soapstone, blue, soft (Independence shale member), 30; limestone, 17.
B. Bennett	SE. ¼ SW. ¼ sec. 20	138	70		Yellow clay, 10; blue clay, 60; limestone, 44; shale gray (Independence), 10; limestone, 14, containing water.
E. Chase	NW. ¼ SW. ¼ sec. 21	130	30		Drift, 30; limestone, 50; limestone and shale, the latter in several beds 4 or 5 feet thick (Independence), 40; limestone, 10.
J. H. Bowman	Sec. 29	136	90		
J. Boglston	SE. ¼ NE. ¼ sec. 31	112	60		
M. Boglston	NW. ¼ sec. 32	112	70		
Wm. Cook	SW. ¼ SW. ¼ sec. 36	136	75		Drift, 75; limestone (Devonian), 45; shale (Independence), 2; limestone, 14.
T. 92 N., R. 13 W. (Warren).					
L. Ladage	SW. ¼ SE. ¼ sec. 4	287	180		Water lowered on drilling of Wixenburg well, 2 miles north.
J. Wilkins	SW. ¼ NW. ¼ sec. 5	150			Ends in water-bearing gravel.
J. Alcock	SW. ¼ SW. ¼ sec. 5	92			Do.
Job Simmons	SE. ¼ NE. ¼ sec. 5	236			Not much sand in well.
L. Armstrong	NW. ¼ NW. ¼ sec. 7	201	196		
F. Pothast	SE. ¼ SE. ¼ sec. 17	317	212		Drift, 212; limestone, 5; shale, 100.
F. C. Pothast	SW. ¼ SW. ¼ sec. 16	352	210		Drift, 210; limestone, 5; shale 135; sandstone with water, 2.
F. Lageshulte	NE. ¼ NE. ¼ sec. 17	236			All in drift.
H. S. Hoover	SW. ¼ SW. ¼ sec. 18	190	185		
Bremer Co. Farm	NW. ¼ SE. ¼ sec. 24	130	105	—30	
M. Sharp	SE. ¼ NW. ¼ sec. 31	130	70		
Chas. Gors	SE. ¼ sec. 32	148	60		No shale.
W. T. Weideman	SE. ¼ SW. ¼ sec. 35	128			Bottoms of Quarter Section Run. Blue clay, 128 feet; sand.
S. Clausing	SW. ¼ NW. ¼ sec. 36	120	(?)		Flowing well.
T. 92 N., R. 12 W. (Fremont).					
C. F. Davies	SE. ¼ SE. ¼ sec. 6	30	12		Lowland, about 2½ miles from an outcrop of Niagaran limestone.
H. Hennings	NE. ¼ NE. ¼ sec. 19	100	100		
Miller	NE. ¼ SE. ¼ sec. 4	89	84		No sand worth mentioning; water in rock.
A. D. Chapin	NE. ¼ sec. 23	110	100	—30	Yellow clay, 7; blue clay, 93; limestone, 10.
T. 92 N., R. 11 W. (Dayton).					
C. Seehase	SE. ¼ SW. ¼ sec. 8	195	190		Divide between Wapsipinicon river and Buck creek.
C. Sell	SW. ¼ NW. ¼ sec. 14	171			Divide between Buck creek and Little Wapsipinicon; ends in sand.

Typical wells in Bremer County—Continued

Owner	Location	Depth	Depth to rock	Head above or below curb	Remarks (log given in feet)
H. Nuss	SW. ¼ SW. ¼ sec. 24	183			Ends in sand.
I. Leverton	NE. ¼ SW. ¼ sec 25	150	145		Yellow clay, 30; blue clay, 115; limestone, 5.
C. Schwahn	NE. ¼ NE. ¼ sec. 27	130			Ends in sand.
N. Mersch	SW. ¼ SE. ¼ sec. 28	148		—30	Ends in sand. Yellow clay, 20; blue clay, 126; sand, 2; typical of wells in this and adjacent sections.
Wm. Franklin	SW. ¼ SW. ¼ sec. 30	109	90	— 9	West bank of Wapsipinicon valley.
Geo. Watts	SW. ¼ NW. ¼ sec. 31	128	120	— 8	West bank of Wapsipinicon valley. Yellow clay, 40; blue clay, 80; hard gray limestone, 8. Water at 128.
F. Pohler	NW. ¼ NW. ¼ sec. 33	150			All clay to water-bearing sand at bottom.
T. 91 N., R. 13 W. (Jefferson and parts of Washington and Jackson).					
Washington Creamery	SW. ¼ SE. ¼ sec. 5	104	81	—90	
F. Soldwisah	NW. ¼ NE. ¼ sec. 6	136	90		
Hans Christian	SW. ¼ SE. ¼ sec. 7	95	25		
M. Sinot	SW. ¼ SW. ¼ sec. 7	65	40		
Chicago Great Western Ry. (E. N. Perry)	NW. ¼ sec. 7	120	45		Yellow clay 10; blue clay, 35; limestone, 75.
Wm. Henning	SW. ¼ NE. ¼ sec. 8	327	156		Blue clay, 156; limestone, 75; shale (Maquoketa), 96. Well unsuccessful; on another part of same farm water was found in drift and at 150 feet.
L. Cory	SE. ¼ SW. ¼ sec. 17	92	60		High hill.
Geo. Baskins	NE. ¼ SE. ¼ sec. 30	214	29		Drift, 29; limestone (Devonian and Silurian), 87; shale (Upper Maquoketa), 95; sandstone, 3.
H. A. Knief	NW. ¼ NW. ¼ sec. 2	214			Ends in sand, all blue clay above sand.
W. H. Knief	SW. ¼ SE. ¼ sec. 2	214			Do.
John Knief	SE. ¼ NW. ¼ sec. 2	220			Blue clay, 210; sand, fine gray and black, with some wood at 210.
Wm. Baskins	NW. ¼ sec. 4	110	100		
W. Farris	SE. ¼ SW. ¼ sec. 23	132	63		Loess and yellow till, 22; blue clay, 41; limestone, 69.
Julius Wille	NE. ¼ sec. 25	122	122		High hill.
M. E. Bloeser	NE. ¼ NE. ¼ sec. 26	82	82		Soft yellow clay, 13; blue clay, 69.
G. B. Briden	NE. ¼ SE. ¼ sec. 33	120	40		Drift, 40; rock, 80.
M. Farrington	NE. ¼ SE. ¼ sec. 35	122	110		Yellow clay and gravel, 30; sand at 30; blue clay, 80; rock, 12.
John Dornbush	1 mile N. and 1 mile W. of Denver.	95		—76	Yellow clay, 20; blue clay, 25; limestone, 50.
T. 91 N., R. 12 W. (Maxfield).					
M. Gauske	NW. ¼ NW. ¼ sec. 1	138	118		Yellow clay, 20; blue clay, 98, to rock.
H. Olendorf	SW. ¼ SE. ¼ sec. 11	95	80		
Geo. Knief	SW. ¼ SE. ¼ sec. 21	80		—10	A few feet above level of flood plain of Crane creek.

Typical wells in Bremer County—Continued

Owner	Location	Depth	Depth in rock	Head above or below curb	Remarks (log given in feet)
Fred Knief	SW. ¼ SW. ¼ sec. 22	50			Ends in sand.
J. P. Ottrogge	SE. ¼ NE. ¼ sec. 23	100			Do.
H. W. Meggerhoff	NE. ¼ SE. ¼ sec. 14	86			Yellow clay, 30; blue clay, 40; sand and gravel, 16.
J. Kolling	NW. ¼ sec. 20	60		—35	Yellow clay, 13; blue clay, 47.
H. Poock	SE. ¼ NE. ¼ sec. 32	273		—73	All blue clay to bottom, where water was found in sand and gravel.
T. 91 N., R. 11 W. (Franklin).					
B. Bierie	SW. ¼ SW. ¼ sec. 7	240	230	—30	Drift clays, 200; "yellowish substance between rock and clay," 30; solid limestone with water, 10.
J. H. Rohrson	NE. ¼ SW. ¼ sec. 7	275		—24	Clay, 200; sand, gray, very fine, dry, 70; gravel and sand with water, 5.
G. Vander Walker	NW. ¼ NE. ¼ sec. 19	130			Ends in sand.
Orrin Station	NE. ¼ NE. ¼ sec. 13	123	98	—40	Yellow clay, 40; blue clay, 58, to rock; water in rock.
R. Rundle	NE. ¼ SE. ¼ sec. 12	128	100	—30	Clay, 100, to rock; water in rock.
Shippy and Harwood	NE. ¼ NE. ¼ sec. 12	98	90		Yellow clay, 50; sand, 10; blue clay, 30, to rock.
Haas Kahler	SW. ¼ SW. ¼ sec. 1	140	120		Yellow clay, 30; sand, 10; blue clay 80 to rock; water in rock.
Wm. Mundt	SW. ¼ NW. ¼ sec. 1	130	100		Drift clays, 80; gray sand with muddy water, 20; rock, 30.
J. T. Nuss	NW. ¼ NW. ¼ sec. 1	120	103		Yellow clay, 30; blue clay, 58; sand, 15; limestone, 17.
Chris. Nieland	SW. ¼ SE. ¼ sec. 2	112	108		Yellow clay, 30; blue clay, 78, to rock; water in rock, no sand in well.
T. 91 N., R. 14 W. (Parts of Washington and Jackson).					
G. W. Bowman	NW. ¼ NW. ¼ sec. 5	112	75		High ground.
Bowman Bros.	SE. ¼ NE. ¼ sec. 4	112	80		
Geo. Moody	NE. ¼ NE. ¼ sec. 9	136	90		Hill.
E. Taylor	SW. ¼ NW. ¼ sec. 11	90	60		
Geo. Curtis	NE. ¼ sec. 13	45	45		Sand, 20; yellow clay, 25.
Chicago Great Western Ry. (J. Carry).	NE. ¼ sec. 12	89	60		
A. S. Mores	NE. ¼ SE. ¼ sec. 1	126	90		Yellow clay, 25; blue clay, 65; limestone, 36.
C. M. Barber	NW. ¼ NW. ¼ sec. 1	151	80		
Allen Sewall	NE. ¼ SW. ¼ sec. 21	126	70		
O. Babcock	NE. ¼ NW. ¼ sec. 22	126	100		
D. Lehman	SE. ¼ NW. ¼ sec. 28	70	40		
School No. 1	NE. ¼ SW. ¼ sec. 34	40			

Typical wells in the Wapsipinicon Valley artesian field, Bremer County.

Owner	Location	Depth	Head	Remarks (logs given in feet)
T. 93 N., R. 11 W. (Sumner and part of Le Roy).		Feet	Feet	
W. B. Barnes	NW. ¼ sec. 18	156	4	Blue clay, 60; fine soft quicksand with some wood at bottom; coarse gravel and water.
William Kuker	SW. ¼ sec. 31	140	— 4	Ends in gravel.
Hiram Lease	NE. ¼ sec. 13	120		Overflows.
T. 93 N., R. 12 W. (Le Roy).				
J. Playman	SW. ¼ sec. 25	85	2½	Near East Wapsipinicon; diameter, 4½ inches.
Louis Testorff	NW. ¼ sec. 26	110	12	95 feet to rock, has now ceased to flow. On East Wapsipinicon.
John Barbknecht	NW. ¼ sec. 28	64	— 5	
Bertha Gericke	NW. ¼ sec. 18	53	— 6	Yellow clay, 10, then gravel which grew coarser to bottom.
Fred Hahn	NW. ¼ sec. 21	16	— 9	
F. H. Friedman	3 miles NE. of Tripoli.	230	2	Ends in sand and gravel. Flows 10 gallons per minute.
T. 92 N., R. 11 W. (Dayton).				
Christian Buhr	SE. ¼ sec. 18		30	
W. C. Gode	SE. ¼ sec. 20	110		Water jetted 15 feet from top of 3-inch pipe.
P. Wynkoff	SE. ¼ sec. 30	75	6	Yellow clay, 10; sand and gravel, 30; blue clay, 25; limestone, 10.
N. Traufler	NE. ¼ sec. 29	121		
Robert Watts	SW. ¼ sec. 31	103	10	Ten or 12 feet above valley floor. Sand, 4; yellow clay, blue clay; limestone at 82; water in rock near bottom.
T. 92 N., R. 12 W. (Fremont).				
C. C. Cook	NE. ¼ sec. 1			Temperature, 47 degrees F.
J. J. Cook	SE. ¼ sec. 1	120	21	About 10 feet above Wapsipinicon bottoms. Diameter, 5⅝ inches. Temperature, 47.3 degrees F. Sand, 8; blue clay, 94; cemented gray gravel, 18.
A. Countryman	SW. ¼ sec. 1			Hillside. Flows only when Cook's well is shut off.
T. 91 N., R. 11 W. (Franklin).				
Peter Watrine	NW. ¼ sec. 27	100		
George Meier	NE. ¼ sec. 5	100		
Anthony Schmeltzer	SW. ¼ sec. 22	93		Hillslope; has now ceased to flow; drilled about 1875.
F. H. Schroeder	SE. ¼ sec. 8			
Henry Fuhr	NE. ¼ sec. 17	92	4	Hillside, 20 feet above Wapsipinicon bottoms. Diameter, 5 inches; drilled in 1903.
William Beal	SE. ¼ sec. 17	98	12	Diameter 2 inches; elevation, 9 feet above Wapsipinicon river. Temperature, 48 degrees F. Loam, 2; sand, 28; blue stony clay, 67¾; gravel, ¼.
B. F. Call	SW. ¼ sec. 15	102		Hillside. Well just overflowed.
J. W. Rommell	NE. ¼ sec. 20	71	10	Diameter, 5 inches. Temperature, 49 degrees F. Flow, 2 gallons through ¾-inch pipe. Yellow sandy clay, 20; blue clay, 51; gravel.

Typical wells in the Wapsipinicon Valley artesian field, Bremer County—Continued.

Owner	Location	Depth	Head	Remarks (logs given in feet)
		Feet	Feet	
Leopold Leistikow	SW. ¼ sec. 20	107	36	Temperature, 47.3 degrees F. Runs 30 gallons per minute through 1½-inch pipe plugged into square iron rod.
George Rommell	NW. ¼ sec. 21	92	4	Temperature, 49 dgrees F. Drill 1¾ gallons per minute through ½-inch pipe.
H. Leistikow	NW. ¼ sec. 29	113		Temperature, 49 dergees F. Drill lifted when water was struck at base of blue till at 113 feet.
H. Leistikow	NW. ¼ sec. 29			Temperature, 49 degrees F. Now a feeble flow.
Charles Liebert	NW. ¼ sec. 29			Formerly used for carp ponds.
M. E. Perry	NE. ¼ sec. 32	100		
Grove Hill Creamery	NW. ¼ sec. 22	106	— 6	Slope.
Carl Hagenow	S. ½ sec. 6	138	—20	30 feet above river. Ends in gravel.

BUCHANAN COUNTY

BY MELVIN F. AREY.

TOPOGRAPHY.

Topographically Buchanan county does not differ greatly from the other parts of the Iowan drift prairie. The inequalities in its surface are a little more pronounced in the southern half than in the northern, for the stream courses trend southward.

Wapsipinicon river crosses the county from northwest to southeast. Its principal tributaries in the county, the Little Wapsipinicon, Otter, Harter, and Pine creeks, enter from the northeast. Buffalo creek, which joins the Wapsipinicon in Jones county, flows for about 25 miles of its course in the eastern part of Buchanan county. Tributaries of the Maquoketa drain almost all of Madison and Fremont townships, in the northeast corner; Spring, Lime, and Bear creeks, branches of the Cedar, drain the southwest corner.

GEOLOGY.

The indurated rocks in Buchanan county are everywhere covered by drift, which attains a maximum thickness in section 4, Buffalo township. Well records indicate that the underlying rock surface is very uneven, partly owing to irregularities in the orginal deposits and partly to preglacial erosion.

Over about 190 square miles of the northeastern portion of the county the drift rests on Silurian rocks, the Niagaran dolomite. Calvin,[1] in his report on the geology of Buchanan county, describes the Niagaran here as a "coarse, granular, vesicular dolomite, interbedded at certain localities with large quantities of chert." In the remaining areas the drift rests on the Wapsipinicon and Cedar Valley limestones (Middle Devonian).

The Wapsipinicon stage, which underlies an area of about 140 square miles in the central part of the county, mainly east of

[1]Ann. report Geol. Survey, vol. 8, 1897, p. 216.

Wapsipinicon river, comprises a lower member (Independence shale member), consisting of dark shale alternating with beds of limestone, and a much thicker and more widespread upper member of brecciated limestones. The lower shale member is ill defined, but it undoubtedly has an important effect in determining the underground water conditions west of the area assigned to it on the geologic map.

The Cedar Valley limestone, which underlies an area of about 240 square miles in the west and southwest portions of the county, is in large part soft, earthy, and somewhat porous, and on exposure weathers quite readily. The middle beds are firmer and carry much less water.

UNDERGROUND WATER.

SOURCE.

The ground-water supplies of Buchanan county are obtained from the Buchanan gravel, which lies beneath the alluvial deposits in the stream valeys and forms local upland deposits; from the Kansan drift; from the sand, gravel, or broken rock underlying the Kansan drift; and from the more or less porous beds of the Devonian and Silurian limestones.

A supply of good water ample to meet all existing demands is found in every part of the county, but in some localities wells must be sunk to a depth of more than 200 feet. The deepest wells are in localities where the drift material is deepest.

Forty or fifty years ago all the water needed for use in the home or for stock, aside from that afforded by springs and surface streams, was obtained from dug wells, which, in the valleys of many of the larger streams, commonly ended in the Buchanan gravel. The water was plentiful and usually was considered wholesome, but was likely to taste of iron, and such wells were liable to become polluted with organic matter washed from the surface. Fortunately improved drainage facilities have rendered the supply somewhat uncertain in many places, compelling a resort to drilled wells ending in the underlying rock. On the open prairie some of the early settlers obtained water by wells ending in the upland phase of the Buchanan gravel, or, more commonly, in the pockets or streaks of gravels in the Kansan drift. Nearly all of these wells were abandoned long ago.

The layers of sand, gravel, or broken rock, underlying the Kansan drift afford a plentiful supply of excellent water, but the water-bearing material is variable. In many places it comprises a bed of sand or gravel from 1 foot to 12 feet thick; in others it is a layer of fragmentary rock mingled with geest or till. In many wells this layer affords the first water, but when the supply obtained is insufficient the driller is compelled to continue into the rock, where second or third flows invariably give ample supplies. So variable, however, is the reported depth to water in rock that it is impossible to refer the source of supply to any particular beds.

In the area immediately underlain by the Niagaran dolomite the drift is in many places thin, and most of the wells obtain water in the rock. The wells range in depth from 100 to 400 feet, and the distances in rock have an equally wide range.

DISTRIBUTION.

In the SW. ¼ section 1, Washington township, a well 100 feet deep ends in gravel just above the rock. Northwest of the drift well 1½ miles a well 110 feet deep is 30 feet in rock. A few rods east of the drift well another 110 feet deep is only 10 feet in rock. A hundred rods southeast of this, in Washington township, a well 104 feet deep is only 4 feet in rock, and another, in Bryan township, a little east of the last, is 123 feet deep, 23 feet in rock.

Calvin[1] reports a well in section 22, Buffalo township, 152 feet deep, ending at the rock in a bed of gravel. In 1898 this well furnished a constant stream of water 1 inch in diameter; it is now reported as no longer flowing.

In the area in which the drift is immediately underlain by the Wapsipinicon limestone wells range in depth from 45 feet (as at Independence) to 136 feet.

A well in the NE. ¼ section 34, Washington township, is 73 feet deep and is in rock for 70 feet. Rock outcrops in many places in a belt 15 to 20 miles long not far from the banks of the river and nearly parallel with it.

[1]Geology of Buchanan county; Iowa Geol. Survey, vol. 8, 1897, p. 253.

In a well in the NE. ¼ section 36, Washington township, rock was found 20 feet from the surface. The well is 136 feet deep, the last 40 feet being chiefly in a gritless clay called "soapstone" by the well driller—undoubtedly the Independence shale member of the Wapsipinicon limestone. The well ends in a flinty rock—the Niagaran—a good water bearer in all this region. In SE. ¼ section 36, a well 80 feet deep, 72 feet in rock, ends in the "soapstone," although, of course, the water comes from the rock just above it.

In the area immediately underlain by the Cedar Valley limestone rock wells range in depth from 85 to 220 feet, and penetrate rock from 5 to 170 feet. North of Wapsipinicon river in this area water is obtained in the Buchanan gravel and accurate data for rock wells are not available.

In Westburg township, in the SW. ¼ sec. 23, a well 220 feet deep, 140 feet in rock, must reach nearly if not quite to the Independence shale member of the Wapsipinicon. In Sumner township a well near the center of section 19 is 155 feet deep, the last 15 feet being in gravel. Another in the northeast ¼ section 22 is 100 feet deep, the last 20 feet being in rock. This well is in the area underlain by the Wapsipinicon. In Homer township two wells are reported. One in the north half of section 3 is 85 fet deep, 5 feet being in rock; the other in the SW. ¼ sec. 23 is 95 feet deep, 15 feet being in rock. In Jefferson township, in the NE. ¼ sec. 2, a well 220 feet deep, 170 feet in rock, undoubtedly ends at the top of the Independence member of the Wapsipinicon.

SPRINGS.

Springs are not very numerous in Buchanan county, and most of those found are seeps from the drift material. In the SW. ¼ sec. 6, Westburg township, however, on G. W. Young's farm near the border of Spring creek valley, a large fissure spring of excellent water emerges at the base of a long, gradual slope 75 feet or more high. No rock outcrops in its immediate vicinity, but the lower beds of the Cedar Valley limestone are exposed in two quarries a mile to the northeast, and it is probable that the water comes from a gravel layer just above the Independence shale member of the Wapsipinicon limestone.

A large spring of good water is reported within the corporate limits of Jesup, on the place of J. D. Land; another is reported on the farm of Mrs. Joseph Patten, two miles northeast of Jesup. Others are reported at Winthrop, on the land of W. H. Eddy, R. L. Wright, R. W. Adams, and Mrs. A. Mulford; and at Rowley, on land of Theo. Hirsh and Robert Eldridge. An old resident of the county asserts that springs are diminishing in importance throughout the county, many no longer being serviceable.

CITY AND VILLAGE SUPPLIES.

Independence.—The public well at Independence (population 3,517) is on Second Street NW., 525 feet west of the river and 10 feet above its level. It is really a cluster of driven wells supplying a common reservoir from which the water is pumped. The first wells were put down in 1886 and improved in 1906.

The wells end on the rock at a depth of forty-five feet and obtain water from the Buchanan gravel. When highest the water from a depth of thirty-five feet stands within 8 feet of the surface; when lowest, within sixteen feet. The strainer is six feet long. The temperature of the water taken in August was 50° F. and does not vary greatly. A compound duplex waterworks pump is used. The maximum yield is 600 gallons per minute, and the supply has not perceptibly varied. The water is soft. The cost of the wells was $2,000 and of the pumps $6,000. The water is used for fire protection and for all general purposes, supplying homes, schools, railroads, canning factory and the State Hospital for the Insane. The daily average demand is 400,000 gallons.

In Rush Park, three-fourths of a mile west of the city well, a well to the Buchanan gravel yields an ample supply of water at a depth of 29 feet. One-half mile west of the Rush Park well a well 77 feet deep, 7 feet in rock, obtains an abundance of water; less than one-fourth of a mile west of this is another well about 112 feet deep, of which 12 feet is in rock. Most of the differences in these wells are due to difference in surface elevation.

The possibility of obtaining an artesian water supply at Independence for the Hospital for the Insane was considered some years ago at the request of the State Board of Control, and forecast was made by W. H. Norton substantially as follows:

Independence is 921 feet above sea level (Chicago, Rock Island & Pacific railway track). After passing the hard limestones of the Devonian the drill will pass into the heavily bedded Niagaran dolomite, where water will probably be found in channels opened by solution and will rise to a level of 25 feet or less below the surface. At about 280 feet the drill will enter the plastic Maquoketa shale, here probably somewhat more than 200 feet thick. The Galena dolomite, Decorah shale, and Platteville limestone will then be traversed, their aggregate thickness being estimated at 350 feet. In these terranes the drill may strike water-bearing crevices. The Saint Peter sandstone, recognized by its whiteness, should be reached about 850 feet below the surface or about 70 feet above sea level. The water from this sandstone will not overflow at the surface and will probably not rise to the level of the water in the formations above. A well to be used for city or institutional supply should be sunk to a total depth of about 1,420 feet. Such a well would tap the water veins of the Prairie du Chien stage (Shakopee, New Richmond and Oneota) and the Jordan sandstone. The drill should not go below the beginning of the glauconiferous shales underlying the Jordan except on expert advice. These deeper waters will also fail to reach the surface. As in all this part of Iowa, artesian water at Independence will be of good quality.

A flowing well situated on a slope in the NE. ¼ sec. 1, Jefferson township, six and one-half miles southwest of Independence, owned by J. E. Cook and R. E. Leach of Independence, was drilled in 1897. It is six inches in diameter throughout and enters rock, but neither the depth to rock nor the total depth could be ascertained. The water rises two and one-half feet above the surface. A decrease in the supply is attributed to bad casing. The water is used for all farm purposes.

Jesup.—The public well of Jesup (population, 697), is 312 feet deep, but the depth in rock is not known. The water is abundant and of good quality.

Winthrop.—The well owned by the village of Winthrop (population, 529) starts 100 feet above the level of Buffalo creek. It is eight inches in diameter at the top, five inches at the bottom, and is 400 feet deep, entering the rock at the depth of 193 feet. The water bed is in rock, undoubtedly the Niagaran dolomite. Water was also found at the top of the rock and at 260 feet. The casing is 8 inches for 198 feet and 5 inches for 61 feet. Water stands constantly at 120 feet from the surface and is pumped by a gasoline engine at the maximum rate of 35 gallons a minute. The supply has not diminished. The well cost $600 and the pump $200. The water is used for all domestic purposes.

CHICKASAW COUNTY

BY O. E. MEINZER.

TOPOGRAPHY AND GEOLOGY.

The surface of Chickasaw county is part of the Iowan drift plain, which is well drained when compared with the areas covered with the younger Wisconsin drift and but slightly dissected when compared with the areas where the older Kansan drift lies at the surface. Numerous small streams cross the county, flowing southeastward in more or less parallel courses.

Over most of the county the deposits of glacial drift form a mantle 100 to 200 feet thick. In some places it is still thicker and in others, as along Cedar and Little Cedar rivers in Chickasaw and Bradford townships and along Little Turkey river in Utica township, where postglacial erosion has been effective, it is entirely lacking. The bedrock consists of limestone, probably all of Devonian age. Its surface, as shown by well sections, is irregular—not unlike the rugged rock surface found farther east in the state, where the glacial drift is absent.

UNDERGROUND WATER.

SOURCE.

The water supply is derived from alluvial and outwash deposits, from glacial drift, from Devonian limestone, and from older limestones—probably Niagaran or those belonging to the Maquoketa shale. Water could also be obtained from still deeper formations of limestone and sandstone.

The alluvial and ancient outwash gravels are found at the surface, chiefly in the valleys. As they commonly occur in low areas and rest upon impervious clays, they are usually saturated with water which they surrender freely to very shallow wells and hence are utilized largely.

Most of the wells in the county obtain water from the glacial drift—either from the upper layer, which is loosely aggregated and somewhat pervious, or from deeper sand and gravel beds which are in fact alluvial and outwash deposits that have been buried beneath bowlder clay. Many wells also penetrate the limestone, the ratio between the number of drift wells and rock wells in different localities varying with the thickness of the drift cover.

The wells in Chickasaw county may be grouped in four classes —driven wells, open wells, drilled drift wells and drilled rock wells. A well of the first class consists merely of an iron pipe with a sand point driven (usually by hand) to a depth seldom exceeding 25 feet into sand and gravel where these materials lie at or near the surface. Such wells are very inexpensive and they furnish much of the supply in the villages located near streams where alluvial and outwash deposits are best developed. Shallow open wells were the principal reliance of the early settlers, but they have generally proven unsatisfactory, both as to quantity and quality of water, and have been largely abandoned for deeper wells. Most of the drilled wells derive their water from sand or gravel in the glacial drift. If the sand is fine it tends to come into the well with the water, in which event it should be cased out and drilling should be continued. In all parts of the county some wells extend into the limestone where large and permanent yields of good water are obtained. Experience shows that it is poor economy to stop the drill before limestone is reached unless the supply coming from the drift is entirely satisfactory. In depth the drilled wells range from about 50 to 330 feet. Their average depth is perhaps between 125 and 150 feet.

In many of the rock wells and deep drift wells the water rises nearly to the surface, and where the altitude is especially low may overflow. An example is afforded by a well on the farm of D. W. Lowry, a mile north of Fredericksburg. This well is 94 feet deep, ends in sand, originally had a head of more than 15 feet, and at present flows about three gallons a minute.

SPRINGS.

Springs are found along the principal streams, especially where the latter have cut through to limestone. In general, however, the county is a level prairie without springs of any consequence.

CITY AND VILLAGE SUPPLIES.

Fredericksburg.—The village well at Fredericksburg (population, 588) is 271 feet deep, the last ten feet of which are in limestone. Its diameter is six inches at the top and four inches at the bottom, and the casing extends to rock. The water stands six feet below the surface, or about 1,070 feet above sea level. The water is pumped to an elevated tank connected to a short system of mains and is used chiefly for fire protection.

Nashua.—At Nashua (population, 1,102) the supply for the public waterworks is taken from Cedar river and is pumped by water power. The system comprises 2 miles of mains, 29 fire hydrants and 162 taps.

New Hampton.—The city well at New Hampton (population, 2,275) is 235 feet deep, the last 100 feet being in limestone. (See Pl. V.) The well is ten inches in diameter at the top and eight inches at the bottom, and it is cased to rock. The water is hard but otherwise of excellent quality and stands forty feet below the surface, or 1,140 feet above sea level. The well is pumped at about thirty-five gallons a minute and is reported to have been tested at 125 gallons. The water is raised into an elevated tank from which it is distributed through two and one-fourth miles of mains to 22 fire hydrants and 198 taps. The daily consumption is estimated to be only 12,000 gallons, although about 500 people, or one-fifth of the population, are reported to be supplied and the water is also used in the locomotives of the Chicago Great Western Railway.

According to W. H. Norton, a deep well at New Hampton would probably obtain a moderate amount of water from the Saint Peter sandstone, which here lies about 750 feet below the surface, and from overlying limestones. A more bountiful supply, however, would be obtained by sinking the well to a depth of 1,250 or 1,350 feet, at which depth the shales of the Saint Lawrence formation should be reached, beyond which drilling will be unprofitable. Owing to the high elevation of the town (1,159 feet above sea level) a flow need not be expected.

CLAYTON COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

Like other counties of the extreme northeastern part of Iowa, Clayton county comprises many geologic formations and has a diversified topography. Measured from the highest divides to the flood plain of the Mississippi, the maximum relief is 650 feet. The massive ridge that divides the valleys of Turkey and Yellow rivers attains an elevation of 1,185 feet between Luana and Monona. The prominent secondary ridge which extends southward between Turkey and Mississippi rivers gradually declines in height from 1,160 feet above sea level near National to 1,060 feet at Garnavillo, and to 1,000 feet west of Guttenberg. The wedge-shaped ridge dividing the Turkey from its affluent, the Volga, reaches a height of 1,250 feet above sea level. South of the Volga the upland reaches the same elevation.

The upland south of the Volga is deeply dissected as far west as Strawberry Point and Edgewood, where it passes into undulating prairie. Here, in the southwest portion of the county, lies an area of Iowan drift in strong topographic contrast to the remainder of the county. Old valleys have been filled and the surface has been molded to gentle constructional sags and swells.

The topography of the remainder of the county is due to long-continued and deep erosion. The northern townships and a belt about eight miles wide along Mississippi river are included in the driftless area. But outside the small area of Iowan drift the older drift forms little more than a veneer and its topographic influence is generally quite negligible. The topography of the entire county outside of the Iowan drift plain, therefore, is that of the driftless area. The ancient base plain of erosion to which this area had been reduced has been uplifted to more than 1,000 feet above sea level. It has been deeply dissected by its master streams and their numerous tributaries. Nowhere are tabular areas of any width left on the divides as remnants of the ancient erosion level. The flanks of the broad interstream areas have been carved to a maze of deep branching and rebranching spurs. The summits have been worn to broad-shouldered, gently rounding crests, which have been utilized as the sites of towns and villages and followed by the railways and the more important roads. On these ridges ground water necessarily stands far below the surface, as it is held only by friction and capillarity above the drainage levels of the adjacent valleys. Wells are deep and windmills are everywhere.

GEOLOGY.

The Pleistocene deposits comprise the loess, the Iowan drift, the Kansan drift, which extends over a large portion of the county, and the blue-black Nebraskan drift, the first deposit of the ice sheets that invaded Iowa. The loess is a fine yellow silt or dust deposit, which mantles the driftless area and the Kansan drift with a maximum observed thickness of about twenty feet. Well records seem to indicate that the loess has a thickness considerably greater than twenty feet in places, but it can seldom be discriminated from other Pleistocene deposits. The drift rests on residual deposits derived by long pre-glacial weathering of the rocks. Where that rock was limestone the deposits consist of red cherty clay; where it was Maquoketa shale the residual material is clay or "soapstone" differing little in composition from the original shale but softer and reddened by the oxidation of its iron constituents.

The Niagaran, the youngest of the rock formations in Clayton county (Pl. V), is everywhere a buff dolomite, as a rule cherty and heavily bedded, cutting under the drill to a sharp limestone sand. Like other dolomites of the county it is liable to be called "sand rock" by the driller, but the cuttings are readily distinguished from the rounded quartz grains of true sandstone by their form and by their brisk effervescence in hot concentrated hydrochloric acid.

The Maquoketa, a variable formation, including clay shales 90 to 100 feet, cherty dolomite beds 30 feet, and basal shales and impure limestones 60 to 180 feet thick, lies beneath the Niagaran. The shaly beds are known as mud rock or soapstone by many of the drillers, or, where somewhat harder, as slate. The Maquoketa forms the bedrock over the uplands of Garnavillo Ridge and of Monona Ridge west of Girard township. In many sections the limestones are dark and more or less argillaceous.

The Maquoketa shale rests on the Galena limestone, the term as here used including the entire body of limestone lying between the Maquoketa and the Decorah shale, which, however, may be locally absent. Beneath the Decorah is the Platteville, consisting of limestone with a shale bed at its base. The Galena limestone has been changed in whole or in part into dolomite. The thickness of the dolomitized portion may reach 200 feet, but the depth to which dolomitization has extended varies greatly. Where dolomitized, the rock is hard, buff, and vesicular, cutting under the drill to yellow sparkling sand or brownish crystalline sand; where undolomitized both the Galena and the Platteville comprise commonly light colored rather soft limestones that are broken by the drill to flaky chips. The total thickness of the Galena, Decorah and Platteville at Elkader measures 285 feet. The combined thickness of the Decorah and Platteville is fifty to sixty feet. The three formations constitute the bedrock over a large part of the upland of the county.

Drillers distinguish as "oil rock" a brown petroliferous shale which is found in many places by the drill and which outcrops near the base of the Platteville; occasionally they report an oily scum in the water when the drill is working in this shale.

The Platteville is underlain by the Saint Peter sandstone, a white rock made up of rounded grains of pure quartz, so little cemented that where quarried in the county for glass sand it is readily broken up by the pick and a stream of water from the hose. Even at Pictured Rocks, below McGregor, where the sand is highly colored and partly cemented by films of the iron oxides deposited by ground water on the grains, the stone is so friable that it is difficult to obtain specimens of any size. The observed thickness of the sandstone in the county ranges from forty to eighty-five feet. The Saint Peter is not always recognized by the drillers. Thus it is said to be absent in the narrow wedge-shaped tongue of upland separating the Turkey from the Mississippi near their junction; at a depth corresponding to the horizon of the Saint Peter, however, there is reported a "river sand," which may be assumed to be the upper layers of the Saint Peter; it underlies a shale, which is probably the basal shale of the Platteville.

Next below the Saint Peter is the Prairie du Chien stage, comprising the strata formerly known as the Lower Magnesian limestone, and consisting of an upper dolomite (Shakopee), an intermediate sandstone (New Richmond), and a basal dolomite (Oneota). The total observed thickness measures 230 feet. It outcrops only north of Guttenberg along the Mississippi bluffs and for four miles or less up the valleys of the tributary creeks. The dolomites of the Prairie du Chien stage are hard, light gray or white, and in many places are cut by the drill into fine sharp limestone sand. They may be distinguished by the driller by their lithologic character and also by their position between the Saint Peter and the Jordan sandstones. The New Richmond sandstone is inconstant, but quartz sand is not uncommon in the dolomite, either as interbedded layers or as disseminated grains.

The Jordan sandstone, the lowest rock outcropping in the county, is made up of pure quartz and is generally of coarse grain. In some layers the grains are firmly cemented with lime carbonate; in others they are incoherent and show little interstitial matter. At McGregor the Jordan is so soft as to be readily excavated with the spade for cellars and vaults in the hillsides. Here it rises 70 feet above the level of Mississippi river, though two miles below the city it sinks from sight below the flood plains of the stream. It outcrops only along the bases of the river bluffs in the northeastern townships, but it underlies the entire county and the waters stored in its pervious layers are accessible to the drill.

UNDERGROUND WATER.

SOURCES.

Gravels at the base of the loess locally yield sufficient water for house supply. Gravels lying between the Kansan and Nebraskan tills and probably at other horizons furnish a supply on the prairie areas of the southwestern part of the county, but are little drawn upon elsewhere. In an area of especially thick drift stretching from the southwestern part of Grand Meadow township northeastward nearly to Postville many wells less than 100 feet deep draw water from drift gravels lying beneath 25 or 30 feet of yellow clay (loess and oxidized Kansan) and then pass into blue till (either unoxidized Kansan or Nebraskan), beneath which sands and gravel are again found on rock, or water is found in broken limestone or residual flints beneath heavy drift.

About 160 feet of the lower portion of the Niagaran outcrops in the southern townships of the county and on the ridge separating the Volga from Turkey river. In this area water is found above the impervious shales of the underlying Maquoketa. On the more level ground of the Iowan plain the entire body of limestone may be saturated with water and yield a good supply to wells that enter the rock a few feet. Thus at Strawberry Point the city supply is obtained from wells drilled only 35 feet into the Niagaran dolomite. Here, as in many places in the southwestern part of the county, the porous and creviced limestone forms a reservoir in which waters descending from the heavy overlying drift have accumulated.

Outside the dissected area covered by the Kansan drift the Niagaran forms escarpments on the summits of the ridges and is drained out for a considerable distance back of these outcrops.

The limestone beds in the Maquoketa furnish an important water supply to villages and farms located on the outcrops of the formation. The water held in the median limestones of the Maquoketa between the upper and lower shales of that formation is under good head, at National rising within 40 feet of the curb.

The Galena and Platteville limestones hold large stores of water in crevices and porous beds, the chief horizons being just above the Decorah shale and above the basal shale of the Platteville. They are utilized by many farm wells in the areas of their outcrops and they form a very important supply on uplands capped with the Maquoketa shale or Niagaran dolomite. At Farmersburg water from the Galena rises within 40 feet of the surface.

The head of the water in the Galena, Maquoketa and Niagaran is considerably higher than that in the underlying Saint Peter, so that as the drill enters the Saint Peter the upper waters often flow through it, and the water in the tube falls. Although the Saint Peter water may not stand high in the well, the supply is copious, permanent, and of excellent quality and is assured to any well in any part of the county which reaches its level.

The Saint Peter sandstone is the lowest formation reached by wells. It is utilized in the northern townships, in the townships adjacent to Mississippi river, and even in the western and central townships as far south as Highland and Cox Creek townships. The dip of the strata carries the sandstone increasingly deeper south and west from its outcrops along the Mississippi, so that on the ridges of the western part of the county between Turkey and Volga rivers it is entered by wells at depths of about 600 feet.

The waters in the underlying Jordan have not yet been tapped in Clayton county. They are, however, everywhere accessible.

FLOWING WELLS.

In the valley of Turkey river, from Elkader down to Motor, wells sunk into the Saint Peter sandstone obtain flowing water. At the fair grounds at Elkader the Saint Peter is reached about 110 feet below the water level of Turkey river, or about 610 feet above sea level; at the James Russell estate farm (section 26, Boardman township) it was reached about 100 feet below the river level; and at Fritz Freitag's, still farther down the valley, at about the same depth. At Motor, four miles in straight line southeast of Elkader, the Saint Peter is 155 feet below the river, or approximately 525 feet above sea level. The head of water, from 40 to 60 feet above the river, encourages drilling at other points in the area. Statistics of these wells are given in the appended table:

Statistics of flowing wells in the Turkey River Valley.

Owner	Location	Year completed	Depth (feet)	Diameter at bottom (inches)	Casing (feet)	Elevation of curb (feet)	Head above curb (feet)	Head above sea level (feet)	Natural flow (gallons per minute)	Pumping capacity (gallons per minute)	Depth to rock (feet)	Depth to Saint Peter sandstone (feet)
City of Elkader (2 wells).	Between High Street and river	1896	186	8, 7	70	*a* 740	20	760	*b* 35	*b* 500	(*c*)	155
Elkader Fair Ass'n.	Elkader	------	167	----	------	*d* 20	----	----	------	------	70	130-135
James Russell estate	Sec. 26, Boardman T.	1905	161	5	*e* 75	*d* 30	28	753	35	------	75	128
Fritz Freitag	Sec. 25, Boardman T	------	155	----	------	*d* 26	34	760	------	------	20	122
Louis Klinck	NE. ¼ sec. 6, Read T.	1906	196	4	*f* 135	*d* 17, *a* 697	40	737	------	------	50	172

a Above sea level.
b Both wells.
c Surface
d Above Turkey river.
e Of 5-inch.
f Of 3 and 2-inch.

If the head of the Saint Peter water is the same up valley as at Elkader flowing wells should be obtained at water level in the river as far as the south line of section 22, Marion township. As the head should increase somewhat upstream. wells in the Saint Peter may yield flows as far even as the Fayette county line. Down the valley from Elkader flows can probably be obtained from the Saint Peter at very moderate depths along the entire valley to its mouth. The large number of springs, the use of open and driven wells tapping alluvial sands and gravels, and the use for stock of the never-failing water of the spring-fed river no doubt have prevented the exploration of the deeper water beds; but the Saint Peter sandstone, with its inexhaustible supplies, should be found within 200 feet below the valley floor at any point from Elkader to the Mississippi.

It is highly probable that in the valley of the Volga flows from the Saint Peter can be obtained from Osborne to the mouth of the stream. The exact depth can not be definitely predicted, as the depth to the Saint Peter is variable, and local changes or reversals of the dip are hidden from view. The data for prediction include an assumed uniform southwestward dip, the elevation of the summit of the Saint Peter at Clayton, at 776 feet above sea level, and the elevation of the same horizon at about 600 feet above sea level 14 miles west-southwest of Clayton; these give a dip of about 12.5 feet to the mile. If the same line be extended 10 miles west-southwest from Elkader to the Volga at the mouth of Deep creek, the elevation of the summit of the Saint Peter at the latter point is found to be 125 feet lower than at Elkader, or 475 feet above sea level. As the level of the river is here 800 feet above sea level, the Saint Peter would be found about 325 feet below the surface. If the water of this sandstone had no higher head on the Volga than at Elkader, it would fall short of reaching the surface by about 40 feet. The fact that the head of the Saint Peter waters increases westward gives ground for hope that as far up valley as Volga flowing wells may be obtained. Taking a similar section from Clayton to Motor and using the data to calculate the water prospects in the Volga valley at Mederville, where the level of the river is 710 feet above sea level, the Saint Peter should be encountered at 485 feet above sea level, or 225 feet beneath the stream level. The head above the river here should be equal to that at Elkader.

SPRINGS.

The springs of Clayton county are exceptionally numerous and large, and come from several well-marked geologic horizons.

The Saint Peter, exposed in a narrow strip along the bluffs of the Mississippi from Guttenberg north, gives rise to oozes and springs where its edges outcrop. The largest springs of the county issue from the base of the Galena limestone. The limestone is creviced and even cavernous; definite channels have been formed by solution by ground water moving down the dip, along the floor of the impervious Decorah shale, to outlets along the valley sides. The same sequence of soluble limestone and underlying shale gives rise to the springs of the limestones of the Middle Maquoketa and those at the base of the Niagaran. Where, as is often the case, these formations are cut by valleys above their bases, these underground streams issue high above the bottom lands in lateral ravines and can be led down to village or farm under considerable head, with power adequate for many utilities. Springs are thus found along the entire course of the Mississippi and along the principal creeks whose valleys have been cut in rock.

CITY AND VILLAGE SUPPLIES.

Clayton.—The village of Clayton (population, 145) utilizes two springs issuing from limestone about 75 feet above the level of Mississippi river, leading the water through one-half mile of mains down the principal street. There are six hydrants from which most of the houses obtain their supply.

Elkader.—The water supply of Elkader (population, 1,181) is drawn from two flowing wells, 182 and 184 feet deep, 25 feet apart, situated on the bank of Turkey river. They pump 500 gallons a minute. A reservoir nearly 300 feet above the town affords ample pressure. There are two miles of mains, 28 hydrants and 200 taps.

If for any reason the city supply should become insufficient it may be greatly increased by drilling to the top of the Saint Lawrence formation, which here should be found 600 or 700 feet below the surface at the city water works.

Guttenberg.—The water supply of Guttenberg (population, 1,873) is obtained from a dug well on the bank of Mississippi river. The water is liable to be contaminated by sewage, which passes readily downward through the sandy alluvium of the river terrace on which the town is built. Water is pumped to a reservoir, giving a gravity pressure of 105 pounds. There are 36 hydrants and four miles of mains.

The elevation at the corner of Herder and First streets is 630 feet above sea level, and an artesian supply might readily be obtained by drilling a well to the Jordan sandstone. The summit of the Saint Peter outcrops near the town at the base of the bluffs bordering the Mississippi. The thickness of the Saint Peter is variable, but a maximum of 85 feet may be assumed. The Prairie du Chien stage, which underlies it, is probably at least 230 feet thick—the maximum thickness where it is exposed along the river bluffs in this vicinity. At 315 feet from the surface the Jordan sandstone should be struck; a well 500 feet deep should draw the available water from this horizon.

As the town is situated well out over an ancient channel of the Mississippi, the drill will first pierce 100 or 150 feet of river sands and gravels. The Saint Peter sandstone will therefore be cut out, and the bed in which the water-tight casing should be securely packed will be the Shakopee dolomite. If shaly beds in the Prairie du Chien are competent to form a cover for the Jordan sandstone the well should flow under moderate pressure.

If a well to the Jordan sandstone should not yield sufficient water by natural flow the supply might be increased by installing an air lift, by sinking other wells to the Jordan, or by deepening the well to the Dresbach or underlying Cambrian sandstones and tapping the water horizons which supply the McGregor wells.

McGregor.—The water supply of McGregor (population, 1,259) is drawn from a well 502 feet deep. Water is pumped to a reservoir affording a pressure of 110 pounds. There are 24 hydrants and two miles of mains.

The first artesian well at McGregor was drilled at the head of Main street, about 60 feet above the lower part of the town, where the deep wells were afterward sunk. The water reached the surface but did not overflow. The well was about 500 feet deep and ended in sandstone.

City well No. 2 (Pl. V), completed in 1877, is situated in the City Park and supplies one of the finest fountains in the state. This well is 1,006 feet deep, six to three inches in diameter, and is cased with four-inch copper to a depth of 40 feet. The curb is 632 feet above sea level; the water rises 62 feet above curb. The flow is 630 gallons a minute. Water was found at a depth of 317 feet and in all sandstone beds below to the bottom of the well. At a depth of 520 feet salt water was found in four feet of white sandstone. The temperature of the water is 54.5° F.

City well No. 3, completed in 1890, is not now used. This well is 520 feet deep and 6 inches in diameter; 3-inch casing extends to 215 feet and is packed at the base with rubber gasket. The curb is 618 feet above sea level, and water originally rose 20 feet above curb. In 1895 the head was below curb. Water comes from a depth of 303 feet. Its temperature is 52° F.

The log of this well shows sandstone with white rolled grains at 250 feet, dolomite from 400 to 415 feet, and white sandstone with well-rounded grains from 450 to 520 feet.

City well No. 4, put down in 1898 by S. Swanson of Minneapolis, is 502 feet deep and 12 to 8 inches in diameter; 12-inch casing extends to 70 feet and 9-inch casing to 200 feet. The curb is about 618 feet above sea level. Water originally rose a foot above the curb, but six months later it stood below the curb. The tested capacity shows that it is sufficient for the city.

No records of the wells at McGregor are available except that afforded by a few samples described below from cursory examination.

Description of samples from city well No. 4 at McGregor.

	Depth in feet
Gravel	35
Sand, yellow, and gravel of pre-Cambrian rocks	50
Sandstone, fine-grained, yellow	60
Sandstone; as above, but coarser	70
Dolomite, dark bluish, drab and lighter drab, crystalline	74- 97
Sandstone, yellow; with yellow dolomitic powder	95
Dolomite, bluish drab, arenaceous; in angular flakes and in sand	97-143
Shale, light blue	143-158
Sandstone, calciferous, or dolomite, arenaceous, light gray	160
Shale, fine, greenish	158-220
Shale, light green	185
Sandstone, light gray, medium coarse; grains well rounded, far from uniform in size	305

Sandstone, pure white, medium coarse; grains well rounded, similar in facies to Saint Peter	350
Sandstone; as above but fine-grained	400
Sandstone; as at 350	415
Sandstone, light gray, calciferous, very fine	444

J. Goedert's well at McGregor has a depth of 294 feet and a diameter of six inches. The curb is 622 feet above sea level and the original head was 22 feet above curb. The well was completed in 1889.

The following carefully kept record of one of the early deep wells at Prairie du Chien, Wisconsin, illustrates the geologic section at McGregor. This record[1] has been modified by assigning the lithologic subdivisions given in the log as originally published to the appropriate geologic subdivisions, and by adding a column showing the depth, in feet, to the bottom of each lithologic unit. The lithologic descriptions have also been transposed, to accord with present survey practice. Another well at Prairie du Chien was sunk to a depth of 1,040 feet without reaching crystalline rocks.

Strata in well at Prairie du Chien, Wisconsin.

	Thickness	Depth
Pleistocene (old channel of Mississippi river, 147 feet thick; top, 627 feet above sea level):	Feet	Feet
1. Sand and gravel	147	147
Cambrian:		
Saint Lawrence formation (115 feet thick; top, 480 feet above sea level)—		
2. Clay, fine, light blue	$\frac{1}{3}$	147$\frac{1}{3}$
3. Limestone, hard, arenaceous	2	149
4. Grit, blue	6	155
5. Shale, bluish green, argillaceous	107	262
Dresbach and underlying Cambrian strata (697 feet penetrated; top, 365 feet above sea level)—		
6. Sandstone, white, friable; alternating with hard streaks [Dresbach]	118	380
7. Grit, blue	35	415
8. Slate rock	65	480
9. Sandstone, reddish and yellow ochery	6	486
10. Shaly rock	24	510
11. Sandstone, white [carrying brine]	4	514
12. Slaty rock	75	589
13. Sandstone	310	899
14. Sandstone, red	45	944
15. Conglomerate; white waterworn quartz pebbles	5	949
16. Sandstone, coarse	10	959$\frac{1}{3}$

Monona.—The water supply of Monona (population, 792) is furnished by two deep wells and a spring. The wells are owned

[1]Wisconsin Geol. Survey, vol. 4, p. 61.

by F. L. Wellman, are twenty-seven feet apart, are under one roof, and supply the Chicago, Milwaukee & St. Paul Railway as well as the town. They were completed in 1885. One is 437 feet deep and the other is 448 feet. The wells are six inches in diameter and are cased for twenty feet. The curb is 1,216 feet above sea level and the head 226 feet below the curb. The combined capacity is 70 gallons a minute. The temperature is 51° F. The water is lowered full depth by continuous pumping.

The water is pumped to a tank affording a pressure of 40 pounds, which is considered insufficient by the town officials. There are three miles of mains, 100 taps, and six hydrants.

North McGregor.—An artesian well, 585 feet deep, belonging to the town of North McGregor (population, 588), is used for fire protection.

The well is six inches in diameter and is cased 180 feet to rock; the original head was about 17 feet above the curb. The temperature is 52° F. In 1904 the flow ceased, but was restored with head of ten feet by recasing.

Driller's log of North McGregor city well.

	Depth in feet
Dolomite, reddish	300
Sandstones, white	350
Sandstone, grayish white	392
Sandstone, white, pure, medium coarse; rolled grains of similar facies to Saint Peter	420
Sandstone, white, fine-grained	423

Strawberry Point.—The water supply for Strawberry Point (population, 1,052) is obtained from two wells, 160 feet deep and ten feet apart, penetrating 125 feet of drift and 35 feet of the underlying Niagaran dolomite. Water is distributed from a standpipe 110 feet high with a capacity of 800 barrels. There are six hydrants and one-half mile of mains.

The sinking of deep wells is not recommended at either Strawberry Point or Edgewood, as the high elevation above sea level of these towns (Strawberry Point 1,217 feet and Edgewood 1,165 feet at Chicago, Milwaukee & St. Paul Railway tracks) makes it impossible to obtain a flowing well. The Saint Peter sandstone should be found at about 350 feet above sea level, judging from its steep dip of more than eighteen feet to the mile from Elkader to Manchester; the Prairie du Chien and the Jordan lie about

500 feet deeper; to reach these waters wells at Edgewood must be sunk to a depth of 1,315 feet from the surface and at Strawberry Point to about 1,365 feet. The water in the Saint Peter sandstone would stand several hundred feet below the surface.

Minor supplies.—Information in regard to water supplies in the smaller villages and the typical wells used throughout the county is presented in the following tables:

Village supplies in Clayton county.

Town	Nature of supply	Depth	Depth to water bed	Source of supply	Head above or below curb	Depth to rock	Springs
		Feet	Feet		Feet	Feet	
Edgewood	Wells	12-16	12		6-8		
Farmersburg	Drilled wells	50-160		Galena to Saint Peter.	—40	30	Small.
Froelich	Drilled wells and cisterns	100-200		Limestone	50-75 100-175	10-25	Large & small
Littleport	Driven wells	15		Gravel			Large
Luana	Drilled wells	70-100	60-90	Limestone	60-70	40	Large & small
National	Drilled wells	50-80	75	Limestone	—45	20	Small
Volga	Dug and driven wells	10-100	15	Sand and gravel.	—10		

WELL DATA.

The following table gives data of typical wells in Clayton county:

Typical wells in Clayton County

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head below curb	Remarks (logs given in feet)
		Feet	Feet	Feet		Feet	
T. 91 N., R. 3 W. (Mallory).							
L. W. Flenniken	NW.¼ SE.¼ sec. 21	180	40	50	Clay	140	500 feet above river. Diameter, 6 inches.
J. H. Brown	NW.¼ sec. 28	589	29	580	Slate rock	400	500 feet above river. Clay, 29; limestone (Niagaran), 200; shale (Maquoketa), 200; limestone (Galena), 160. Yields 3 gallons per minute. Diameter, 5 inches.

Typical wells in Clayton County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head below curb	Remarks (logs given in feet)
R. M. Peck	SW.¼ sec. 28	237	80	140		180	Diameter, 6 inches.
W. C. Barnhart	Sec. 21	70	24	65		55	Do.
T. 92 N., R. 6 W. (Sperry)							
F. E. Ambrose	NW. ¼ sec. 14	146	31	145	Limestone	31	Water at about 55. Diameter, 6 inches.
T. 93 N., R. 6 W. (Highland).							
C. Duff	Sec. 20	56	25		Sandstone	30	Valley. Diameter, 6 inches.
Henry Baars	SW.¼ NE.¼ sec. 36	665				415	Yellow clay, 15; rotten yellow sandstone (Niagaran), 20; blue shale, 205; limestone, 350; shale, 10; limestone, 35; clear sandstone, Saint Peter, 30. Bottom about 495 feet above sea level.
John Rinkerts	1 mile west of Baars.	527			do.		
T. 92 N., R. 5 W. (Cox Creek).							
Henry Jennings	Sec. 5	120	100	110		100	Diameter, 5 inches.
Town	Volga	25		20	Gravel	20	Flood plain of Turkey river. Diameter, 3 feet.
L. Beute	SW.¼ NE.¼ sec. 11	515				265	Struck Saint Peter sandstone.
Henry Leubke	SE.¼ NW.¼ sec. 4	589			Sandstone	349	Yellow clay, 60; shale, 140; limestone, 371; shale, green, 8; Saint Peter sandstone, 10. Bottom about 521 above sea level.
T. 95 N., R. 6 W. (Grand Meadow).							
Charles Shultz	SW.¼ SW.¼ sec. 21	165	160	160	'Loose flint' residual.		Yellow clay, 20; quicksand, 140; loose flint (residual), 5.
T. Gordon	Sec. 6	66			Gravel		Blue-black till from 40 to 60, gravel below.
T. 94 N., R. 6 W. (Marion).							
	NE.¼ SW.¼ sec. 16	150				115	Ravine; all limestone from curb.
	SW.¼ NW.¼ sec. 4	75	20			57	Sand rock at 20; ends in blue clay.
	NW. ¼ NW. ¼ sec. 11.	115	80		Sandstone	20	Yellow clay, 40; blue till, 40; sandstone, 35.
Mrs. Bowder	NW. ¼ NW. ¼ sec. 18.	237	60		Limestone	225	Ridge. Drift, 60; blue shale, 100; sand rock, 77.
W. Houg	NW. ¼ NW. ¼ sec. 23.	120			do.	100	Ridge. "Sandstone" brown, 50; shale, blue, 50; limestone, 20.
T. 95 N., R. 4 W. (Girard).							

Typical wells in Clayton County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head below curb	Remarks (logs given in feet)
J. Smyzer	3½ miles east of Monona.	404					To sandstone, 288.
J. W. Tewes	NW.¼ NE.¼ sec. 17	405	45		Sandstone	375	Water in Saint Peter sandstone; temp. 48 degrees F. Diameter, 6½ inches.
T. 92 N., R. 2 W. (Part of Jefferson).							
Peter Burr	SW. ¼ SW. ¼ sec. 29.	370	33	370	Sandstone	359	Clay, 33; limestone, 222; Saint Peter (shale and sand, clean sand at bottom), 115. Water at bottom of Saint Peter in large supply.
A. E. Schroeder	NW. ¼ SW. ¼ sec. 7.	275	40	180-225	Limestone on shale	185	Loess, 40; limestone, 185; shale blue, fossiliferous, 6; limestone, 39; shale, blue, 4; Saint Peter sandstone, 1.
Gustav Ditmar	NW.¼ SE.¼ sec. 30	275	40	270	On shale	215	Limestone, 230; shale 5. Water in shale (large supply).
L. Mueller	NW.¼ NE.¼ sec. 31	257	40	254	Limestone	167	All limestone below 40.
N. Niehause	NE.¼ SW.¼ sec. 33	367				349	Curb about 940 above sea level. Clay, 40; limestone, 250; shale, 10; light colored sand from 340 to 342; limestone from 342 to 360; shale, blue, 7; footing in reddish sand and gravel.
T. 92 N., R. 3 W. (Part of Jefferson).							
William Ball	NE.¼ NE.¼ sec. 28	403	30		Limestone	183	Oil rock at 380; water above oil rock; a weak vein.
P. J. Schmidt	N. ½ SE. ¼ sec. 15	120	80	120		60	Clay, 80; slate, 20; brown hard rock, 20.
T. 93 N., R. 5 W. (Boardman).							
	SE. ¼ sec. 8	449	40			244	Divide. Yellow clay, 40; soapstone, 40; slate with water, 20; soapstone, limestone, Saint Peter, at 435.
George Cassuth	SE.¼ NW.¼ sec. 21	219	30	215	Slate		Yellow clay, 24; sand with a little water, 4; yellow clay, 2; soapstone, 85; slate with water, 15; soapstone, 20; limestone to 219.
T. 93 N., R. 4 W. (Read and Part of Garnavillo).							
S. Schmidt	SE. ¼ SE. ¼ sec. 7	398	20		Sandstone	344	Ridge. Yellow clay, 20; limestone, 210; soapstone, 70; slate, 30; shell, 8;

Typical wells in Clayton County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head below curb	Remarks (logs given in feet)
							hard limestone, 40; blue soapstone, 5; Saint Peter sandstone, 15. About 611 above sea level.
T. 95 N., R. 5 W. (Monona).							
—— Selder, Luana	----------	80	------	------	Gravel ------	------	Water-bed gravel below blue-black till.
T. 91 N., R. 4 W. (Elk).							
----------	Sec. 33 ----------	213	92	------	------		
T. 91 N., R. 2 W. (Millville).							
John Minger ------	SW.¼ NE.¼ sec. 15	233	45	------	Hard rock --	188	Hill.
J. S. Graykill------	NW.¼ NE.¼ sec. 23	266	------	------	------	246	Insufficient supply.
John Patrick ------	NW.¼ SE.¼ sec. 23	66	------	------	Rock ------	18	
William Smith ------	NW.¼ NE.¼ sec. 15	220	------	------	------	200	Large supply.
A. Brockman ------	SE.¼ NW.¼ sec. 10	30	------	------	Sand ------	------	Dug well on bottoms.
J. Beeker ------	NW. ¼ NW. ¼ sec. 16 ------	290	40	------	Limestone --	268	Footing in shale (Platteville).
L. Troester ------	S. ½ sec. 7------	90	30	------	---- do. ----	30	60 feet solid Galena limestone; house well.
J. T. Collins------	NW.¼ NE.¼ sec. 17	140	------	------	------	100	Loess, 30; blue clay, 70; black hard slate from 117 to 140.
E. Smith ------	NE.¼ SW.¼ sec. 36	225	30	------	------	------	Loess, 24; red flint (residual), 6; limestone, 188; slate, 7.
A. Andrus ------	SE.¼ SW.¼ sec. 26	330	30	------	------	205	Drift, 24; red flint, 6; soft limestone, 110; light colored limestone, 185; shale, 5.
T. 95 N., R. 1 W. (Buena Vista).							
J. Hafel ------	SW.¼ SW.¼ sec. 20	255	------	------	------	215	Shale, 120; limestone, 60; oil rock; water in limestone below oil rock.
—— Hafel ------	NW.¼ SE.¼ sec. 20	243	38	------	------	------	Limestone from 38 to 235; shale, 5; fine soft sandstone of white quality, 3; water at 170.
Frank Nagel ------	NW.¼ NE.¼ sec. 20	280	30	275	Limestone --	250	All limestone; water in crevice.
R. Meuth ------	NE.¼ sec. 21------	230	30	220	------	200	Loess; residual red flints; limestone to 220; blackrock hard, in chips, with water, 10.
A. Weeks ------	SE. ¼ sec. 22------	220	30	------	------	180	Clay, 30; limestone, 130; dark rock, 60.
Charles Wales ------	NW. ¼ NW. ¼ sec. 31 ------	167	------	70	------	75	Under bluff; light-colored clay, 60; black slate, 10; dark limestone, 30; oil rock, 5; limestone, 1; oil rock with blackjack, 5; limestone with pockets of blackjack, 38; glass rock, 18; strong vein.

DELAWARE COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

The topography of Delaware county is somewhat complex. In the northern part lies a rugged upland of loess-covered Kansan drift, dissected in interglacial time by the headwaters of streams tributary to Turkey river. A similar tract of maturely dissected Kansan extends from Earlville and Delhi south along Maquoketa river. and other insular patches of upland occur in Richland and Coffin Grove townships.

Bordering or surrounding these areas of rugose uplands lies the plain of Iowan drift, its fairly level surface diversified with low, ice-molded swells of stony clay and glacial gravels.

GEOLOGY.

Three drift sheets are represented in the county. The Iowan drift sheet, the uppermost of the three, is comparatively thin. The lowest, the Nebraskan, is revealed in wells where an old soil bed (Aftonian) separates the basal stony clay from the overlying Kansan drift. The Nebraskan and the Kansan tills together make up the great bulk of the drift deposits of the county. The loess, a yellow silt, too fine for sand and too coarse for clay, is spread as a blanket over the dissected surface of the Kansan uplands.

In well records it is very difficult to distinguish the different deposits of the drift. Even the pebbleless, soft yellow loess may not be set apart from the brighter yellow, hard, and stony Kansan drift on which it lies, although their discrimination on the spot is extremely easy. In the contents of the slush bucket it is hardly possible for the driller to distinguish the oxidized Iowan drift from the still more highly oxidized Kansan till, and yet more difficult to separate the blue unoxidized Kansan from the blue Nebraskan drift on which it rests. In places, however, the Kansan till is covered with old, rusted glacial gravel (Buchanan), which separates it from the Iowan drift. In some places this gravel has been left heaped in hills; in others it underlies low plains or occurs as outwash in the river valleys.

The basement rocks underlying the county belong to three formations. The youngest are Devonian limestones, which are supposed to lie beneath the heavy cover of drift over an area comprising about seven square miles in the extreme southwestern part of the county. Next in age is the Niagaran dolomite, which forms the bedrock over nearly the entire county. It outcrops in many sections and, where concealed from view by the mantle of drift, is discovered beneath it by the drill. The lowest rock exposed is the Maquoketa, a bluish, plastic shale, which outcrops in the deep valleys of Elk creek and Little Turkey river and is reached by wells in different parts of the county (See Pl. VI).

UNDERGROUND WATER.

SOURCE AND DISTRIBUTION.

Drillers in Delaware county, as in other counties of eastern Iowa, report a general lowering of the surface of permanent ground water during the last two or three decades, leaving dry or inadequate the drift sands which in earlier years were sufficient to the needs of the population. Twenty years ago on the Iowan drift plains about Manchester ground water stood within 50 to 75 feet of the surface and wells of that depth sufficed; at present most wells in that area exceed 100 feet and penetrate the rock. In many wells which have not gone dry a distinct lowering of water has been noticed, amounting to as much as 20 feet.

Exceptions to the present insufficiency of the drift strata may be noted where drift sands are unusually thick, as in buried river channels, where they are unusually extensive overlying the rock, and where outwash sands whose upper surface lies little above the level of a river are well supplied with water from higher ground adjacent. Thus on the east side of Honey creek, from Manchester nearly to Millheim, driven wells in sand are used. An ancient bed of the Maquoketa at Rockville, filled to a depth of 80 feet with sand, supplies farm wells in that locality. At Manchester, where Maquoketa river now flows over a bed of rock, a wide ancient channel, 100 feet deep and filled with sand, lies but two blocks from the river banks and is utilized for many house wells. At Sand Springs also wells are sunk through sand to a depth of 75 feet, where they reach the Niagaran dolomite, and obtain water that rises within one foot of the surface. On the prairie southwest of Petersburg wells still find water in glacial gravels overlying rock. A belt of exceptionally thick drift passes east of Ryan through Hazel Green and into southwestern Milo township. Several wells reported from this belt show drift from 200 to 240 feet thick, and each of these wells enters rock for a few feet, probably to secure attachment for the casing.

The drift over most of the northwestern part of the county is chiefly of a hard blue stony clay or till, with included sand veins four to six feet thick. In places it is 15 feet thick, but at present it does not afford a supply of water adequate for the ordinary farm. Most of the wells are sunk to the underlying rock.

Over much of the county, especially in the northern and eastern portions, where the Niagaran approaches or reaches the surface, water is found at varying though usually moderate depths in the country rock.

In the southeastern part of the county wells commonly find water above the base of the Niagaran and the summit of the underlying impervious Maquoketa shale. Northwest of Monticello few wells exceed 80 to 100 feet. As the Niagaran in the southeast townships attains a thickness, according to some well sections, of 160 to 200 feet, wells not infrequently find water at depths of 80 and 100 feet at a greater or less distance above the floor of the shale. Six miles southeast of Delhi a well entered the Niagaran at 40 feet; at 200 feet it encountered loose, caving, shelly rock; and at 280 feet it struck a mud-rock shale, both the caving rock and shale being referable to the Maquoketa. The mud-rock shale was penetrated to a depth of 120 feet, the total depth of the well being 400 feet. The boring was abandoned before it reached the Galena limestone, and a new well, located 50 feet from the first, found plenty of good water on the shale.

In Delhi township, occupied largely by an area of Kansan drift, the thickness of the drift varies from practically nothing to 240 feet and wells find water in the subjacent limestone at depths of 60 to 225 feet from the surface of the ground.

In the northeast townships of the county much the same conditions prevail as in the southeastern. Wells 100 feet deep draw water from glacial sands on the Iowan prairie southwest of Petersburg, where rock is reached as a rule. In Colony township, in an area of well-dissected Kansan drift mantled with loess, blue Kansan till is heavy and wells find water in the subjacent limestone.

The Maquoketa shale, brought up toward the north and east, by the general southwestward dip of the strata, outcrops at Rockville and in the valleys of Little Turkey river and Elk creek. Hence the depth of wells in the Niagaran decreases toward Dubuque and Clayton counties. In northern Colony and Elk townships the deepest wells penetrate the Maquoketa shale and resemble those described in the adjacent parts of Clayton county.

In the four northwestern townships no wells are reported as reaching the Maquoketa, all finding water either in Niagaran dolomite at different depths or, less commonly, in the sands and gravels of the drift. Wells seldom exceed 160 feet in depth, although some are as deep as 265 feet, penetrating the Niagaran to 200 feet.

In the southwest townships the drift thickens toward the south and west. The deep drift east of Ryan, due probably to a buried channel, has already been noted. To the east of this "deep country," as the drillers term it, the rock rises to the surface at Maquoketa river. A mile west of the buried channel rock approaches within 50 feet of the surface of the Iowan drift plain. In southern Prairie township wells are drilled from 70 to 100 feet and more in the Niagaran dolomite after passing through from 80 to 120 feet of drift. In Adams township the same conditions prevail, except that in the southwest corner of the township the bedrock belongs to the Devonian system.

The deeper Ordovician and Cambrian sandstones lie too far below the surface to be reached with profit, except for the water supply of the largest towns. It is from these affluent sources that the supply of Manchester is drawn, the artesian well of that city being 1,870 feet in depth. (See Pls. VI and VIII.)

SPRINGS.

Delaware county is favored with many large springs in all parts except the southwestern, where the country rock is deeply blanketed with drift and the area has suffered but little dissection.

A well-marked spring horizon occurs in the Niagaran dolomite below the base of the Pentamerus zone, which lies 150 feet above the summit of the Maquoketa shale along Elk creek. From this horizon issue the copious springs which supply Spring creek in southern Delaware and northern Milo townships, and the waters of which are utilized by the large fish hatchery of the United States Bureau of Fisheries near Manchester. Other large springs from the same horizon occur near Hopkinton, near Millheim, and at different points in Honey Creek and Delaware townships along the valleys of the creeks tributary to the Maquoketa. In Richland township many springs issue from the same beds at the base of the picturesque limestone cliffs north of Forestville known as the "Devil's Backbone."

A still lower horizon is at the contact of the pervious and creviced Niagaran dolomite with the Maquoketa shale. The underlying impervious bed of shale collects the water descending through the limestone and leads it down the dip to outlets where valley and ravine have trenched the strata. Dissolving little by little the rock through which it seeps, the ground water has developed a system of passageways in the transition beds overlying the shales and issues from its trunk conduits in powerful springs. The many springs along Elk creek and its numerous branches in Elk and Colony townships emerge at this horizon.

A few examples of these fine springs must suffice. The spring of L. Schnittjer, section 26, Delhi township, issues with a temperature of 52° F. from the Niagaran. The water is lifted to a convenient level for domestic use and the watering of stock by a hydraulic ram—a device also used by other farms in the vicinity. The Silver Spring Creamery, Delhi, uses two springs issuing from the Niagaran dolomite at the bottom of a ravine. Like most of the springs of the county the water carries no sediment, and its flow and clearness are not affected by storms or wind. The water flows through the creamery where it is used for all purposes. The temperature is stated to be about 50° F. Big Spring, section 3, Colony township, issues from the base of the Niagaran, as does the spring of J. D. Chase, of Greely, which flows from 100 to 120 gallons a minute. From the same horizon issues the spring of J. C. Odell, section 16, Elk township, whose discharge is ten barrels or more a minute and whose water is carried by a flume 40 rods long and develops 30 horsepower. It is utilized to run a gristmill. The temperature is stated to be 48° F.

CITY AND VILLAGE SUPPLIES.

Earlville.—Earlville (population, 552) draws its water supply from a well and uses it chiefly for fire protection. The pressure is 39 pounds and there are 11 hydrants and one mile of mains.

Hopkinton.—Water for Hopkinton (population, 797) is obtained from a drilled well 83 feet deep and 8 inches in diameter. Water is found in the Niagaran dolomite, which the well enters at 30 feet. The Maquoketa shale was reached by the well. Water rises within 40 feet of the surface and is lowered but 5 feet under pumping. It is pumped by gasoline engine to a tank, which supplies a gravity pressure of 55 pounds. There are 3,300 feet of mains and 7 fire hydrants.

Manchester.—The supply for Manchester (population, 2,758) is drawn from an artesian well 1,870 feet deep. (See Pls. VI, VIII.) The well is 10 inches in diameter to 260 feet, 7 inches to 890 feet, and 6 inches to 1,650 feet. A 7-inch casing extends from 260 to 890 feet, and a 5-inch casing from 1,300 to 1,650 feet. The curb is 926 feet above sea level and the head is 14 feet below the curb; with the Niagaran waters cased out the head is 150 feet below the curb. The tested capacity was originally 200 gallons a minute and is now 250 to 300 gallons a minute from depths of 1,200 to 1,296 feet (Jordan). No water was found below 1,500 feet. No repairs have been made. The temperature after 10 hours' pumping was 48° F. The well was completed in 1896 by J. P. Miller & Company.

Previous to the completion of this well the water supply of Manchester had been an excellent spring, situated near the business portion of the town on the banks of Maquoketa river. A reservoir excavated in solid Niagaran rock receives the water of the spring, and to develop the flow to the utmost several wells of moderate depth have been drilled within it. As the water was insufficient to supply the increasing population of the town, it was wisely decided to sink an artesian well, and a site was selected adjoining the reservoir and some 24 feet higher than the water in it.

While the drilling was in progress to at least a depth of 1,400 feet, water stood in the shaft at about 14 feet from the surface, and there were indications that this height was due to the influx of water from the spring. When water-bearing strata were reached at 1,200 feet and below, and the well was cased to 260 feet, the water dropped to 150 feet from the surface. On removing the upper casing to a depth of 260 feet, the water again rose within 14 feet of the curb, and on the final pumping test of the well the spring adjacent nearly ceased flowing. The well, therefore, receives a supply of water from the Niagaran dolomite from the same source as that of the spring. The Saint Peter is cased out, if the record is correct, and it is not known whether or not it is water bearing. The main flow seems to come from the Jordan sandstone, from 1,200 to 1,296 feet. Below 1,500 feet it is reported that no water was found—a remarkable fact, as the drill penetrated the entire thickness of the Dresbach sandstone.

The lower flow alone was tested with a pump throwing 75 gallons a minute for 24 hours without lowering the water. On the final test of all waters with a pump throwing from 160 to

200 gallons per minute from a 7-inch pipe 200 feet deep, the water soon sank to 33 feet from the surface and there remained during the entire test of 20 consecutive hours.

The pumping cylinder is now set 200 feet below the surface in the well and the engines also pump from the spring reservoir. When the deep-well pump is in operation no water flows from the spring and the reservoir is drained. When the pump of the spring is working at its maximum the pump of the deep well jerks as if sucking air. The spring alone supplies about 40,000 gallons a day. The deep well pumps from 250 to 300 gallons a minute all day without difficulty. In this connection should be noted the abnormally low temperature of the water pumped from the deep well after 10 hours' pumping and some 20 minutes after the pumping from the spring had ceased. Without question the well receives from the Niagaran a large amount of water of low temperature.

Record of strata in city well at Manchester.

	Thickness	Depth
Silurian:		
Niagaran dolomite (225 feet thick; top, 926 feet above sea level)—	Feet	Feet
Dolomite, buff; 6 samples	140	140
Dolomite, blue-gray, highly cherty; 6 samples	60	200
Dolomite, blue-gray, cherty, pyritiferous, slightly argillaceous	25	225
Ordovician:		
Maquoketa shale (205 feet thick; top, 701 feet above sea level)—		
Shale, blue, gray, green and drab; 18 samples	145	370
Magnesian limestone or dolomite, dark drab, subcrystalline, somewhat argillaceous, in flakes; 2 samples	14	384
Shale, blue and gray-green; 7 samples	46	430
Galena limestone to Platteville limestone (354 feet thick; top, 496 feet above sea level)—		
Limestone, magnesian, dark drab, argillaceous	10	440
Limestone, light gray; earthy luster, briskly effervescent; 16 samples	106	546
Dolomite, light yellow-gray, subcrystalline; stained with ferric oxide in minute rounded spots; much of the superior limestone in small fragments	10	556
Limestone, light and darker blue-gray; generally rather soft; earthy luster; in flakes and chips; 20 samples	142	698
Shale, bright green, fossiliferous, containing Orthis perveta Conrad, Strophomena trentonensis W. and S., and bryozoa (Decorah shale)	5	703
Limestone, light blue-gray, fossiliferous	8	711
Limestone, light blue-gray, earthy to crystalline; 11 samples	66	777
Shale, green, somewhat calcareous	7	784
Saint Peter sandstone (33 feet thick; top, 142 feet above sea level)—		
Sandstone, with small chips of limestone, in which no embedded grains are noticed	3	787
Sandstone, as above, but free from admixture; 4 samples	30	817
Pairie du Chien stage—		
Shakopee dolomite (65 feet thick; top, 109 feet above sea level)—		
Dolomite, buff and gray; angular sand, mostly quartz sand, probably from above; 3 samples	18	835
Dolomite, light gray	42	877
Dolomite, slightly arenaceous	5	882
New Richmond sandstone (49 feet thick; top, 44 feet above sea level)—		
Dolomite, highly arenaceous, grains rounded and some enlarged by crystalline facets; 2 samples	11	893

Record of strata in city well at Manchester—Continued

	Thick-ness	Depth
Dolomite, gray, arenaceous; some light drab shale	6	899
Dolomite, arenaceous; some highly arenaceous shale; 2 samples	19	918
Sandstone, calciferous	3	921
Dolomite, gray, arenaceous, with argillaceous powder	10	931
Oneota dolomite (275 feet thick; top, 5 feet below sea level)—		
Dolomite, gray; 8 samples	54	985
Dolomite, light gray, arenaceous; 3 samples	24	1,009
Dolomite, gray; arenaceous from 1,100 to 1,103 feet; 27 samples	170	1,179
Dolomite, arenaceous, gray	5	1,184
Dolomite, highly arenaceous, or sandstone, calciferous; 4 samples	22	1,206
Cambrian:		
Jordan sandstone (90 feet thick; top, 280 feet below sea level)—		
Sandstone, white; grains rounded and ground, with considerable diversity in size; 7 samples	50	1,256
Shale, highly arenaceous and calcareous	4	1,260
Sandstone, as at 1,256; 5 samples	36	1,296
Saint Lawrence formation (242 feet thick; top, 370 feet below sea level)—		
Dolomite, gray; some sand, probably from above	20	1,316
Sandstone, calciferous, or highly arenaceous dolomite	15	1,331
Dolomite, light yellow-gray	5	1,336
Dolomite, gray; in fine sand mixed with considerable quartz sand; 2 samples	10	1,346
Dolomite, light gray; in clean chips; a little sand from above	10	1,356
Dolomite as at 1,346; 2 samples	16	1,372
Marl, arenaceous, argillaceous, and calcareous; in fine green-gray powder; 6 samples, all of a pulverulent powder, seen under the microscope to be composed of minute angular particles of quartz, dolomite, and chert, with much argillaceous material; glauconiferous	153	1,525
Sandstone, fine-grained; in greenish yellow powder; argillaceous	13	1,538
Dresbach sandstone and underlying Cambrian strata (332 feet thick; top, 612 feet below sea level)—		
Sandstone, white; grains fine and rounded	22	1,560
Sandstone; greenish argillaceous material mixed with drillings	13	1,573
Sandstone, fine; light buff from ferruginous stain	6	1,579
Sandstone, fine	19	1,598
Sandstone, coarser; uniformly rounded, smooth surfaced gains of limpid quartz	13	1,611
Sandstone, white	79	1,690
Sandstone, yellow, glauconiferous; said to be argillaceous	25	1,715
Shale, light blue, arenaceous, calcareous, somewhat glauconiferous	155	1,870

The water is pumped to a standpipe (capacity, 105,750 gallons) and distributed under domestic pressure of 50 pounds and fire pressure of 80 to 110 pounds, through 6 miles of mains, to 38 fire hydrants and 350 taps.

Ryan.—The water supply of Ryan (population, 511) for fire protection is drawn from a drilled well 258 feet deep, which enters rock at 90 feet. Water was found at 150 feet and rises within 60 feet of the surface. The capacity of the well is 150 gallons a minute. Water is distributed from an air-pressure tank under pressure of 60 pounds. There are 400 feet of mains and five hydrants.

Minor supplies.—Information concerning the water supplies of the smaller communities in the county is presented in the following tables:

Village supplies in Delaware County.

Town	Nature of Supply	Depth	Depth to water bed	Head below curb	Source of Supply
		Feet	Feet	Feet	
Compton	Driven and drilled wells	12-150		10-20	
Colesburg	No report				
Delhi	Drilled wells	75-100		65-80	Niagaran dolomite.
Dundee	Wells	40-250	70-100	20-40	Do.
Greely	Drilled wells	70-200	90		Do.
Masonville	Deep wells	65-140	90-140	50-100	Do.
Oneida	Wells	50-125	60		Do.
Sand Spring	Driven and drilled wells			1 in.	Sand.
Thorp	Drilled and dug wells	15-100			Niagaran dolomite.

WELL DATA.

The following table gives data of typical wells in Delaware county:

Typical wells in Delaware County.

Owner	Location	Depth	Depth to rock	Source of Supply	Head below curb	Remarks (Log given in feet)
		Feet	Feet		Feet	
T. 87 N., R. 6 W. (Adams)						
T. Williamson	4 miles north of Coggon.	305	55		55	20 feet away a well sunk to 160 feet found no water, rock being struck at 108 feet.
W. Montgomery	4 miles north and 1 mile east of Coggon.	108	108			108 feet to water bed.
R. Platten	4 miles northeast of Coggon.	140	80			
T. Henderson	4½ miles northeast of Coggon.	68	68		18	68 feet to water bed.
A. Swidle	Silver creek	70	30			70 feet to water bed.
Charles Beny	Northwest of Ryan	350	200+			Sandy soil, 2; clays to 6; soil, 8; Niagaran, buff dolomite, 130; limestone, nearly white, 20; blue shale, Maquoketa, 40.
	S. ½ sec. 35	207	20			207 feet to water bed.
	NE. ¼ NE. ¼ sec. 23	130	120			Mostly blue clay to rock.
	SW. ¼ SW. ¼ sec. 1	160				All in drift.
	SW. ¼ NW. ¼ sec. 35	280	120			
T. 87 N., R. 5 W. (Hazle Green)						
William Porter	3 or 4 miles east of Ryan.	262	260		110	
	NW. ¼ SW. ¼ sec. 28	205	200			High ground. Mostly blue clay to rock.
G. Abbey	NW. ¼ NE. ¼ sec. 32	160	155			Somewhat lower ground than last.

Typical wells of Delaware County—Continued

Owner	Location	Depth	Depth to rock	Source of Supply	Head below curb	Remarks (Log given in feet)
		Feet	Feet		Feet	
----------	NE. ¼ SE. ¼ sec. 28	242	240	----------	40	Much lower ground than last two.
T. 87 N., R. 4 W. (Union and Part of South Fork).						
James O'Neil ----	Southwest of Hopkinton.	200	80	Niagaran dolomite	----	All blue clay to rock.
T. 87 N., R. 3 W. (Part of South Fork).						
Charles Root----	NW. ¼ sec. 18----	200	10	----------	----	
Jacob Land----	Northeast of Sand Spring.	125	65	----------	----	
—— Mauser----	2½ miles south of Worthington.	208	16	----------	----	
----------	NW. ¼ NE. ¼ sec.1	162	20	----------	----	Sand, 20; limestone, 140; shale, 2.
T. 88 N., R. 5 W. (Milo).						
----------	NE. ¼ NE. ¼ sec. 29	215	214	----------	----	High ground.
----------	SW. ¼ SW. ¼ sec.28	190	----	Gravel----------	----	Lower ground. Ends in gravel 60 feet lower than the preceding and following.
—— Haynes----	NW.¼ NW.¼ sec. 33	210	200	----------	----	Nearly all in drift.
----------	NW. ¼ NW.¼ sec.32	145	130	----------	----	
----------	NW.¼ NW.¼ sec. 30	70	50	----------	----	Low ground.
----------	SW. ¼ SW. ¼ sec.19	60	60	----------	15	Low ground; clay from top to rock.
Charles Thorpe---	7 miles south of Manchester.	180	150	----------	----	Blue clay to rock.
----------	SW. ¼ SW. ¼ sec. 2	85	15	----------	----	
T. 88 N., R. 6 W. (Prairie)						
----------	NW.¼ NW.¼ sec. 21	100	90	----------	----	
Lee M. Smith----	4 miles southwest of Manchester.	100	80	Limestone----------	----	Blue clay to rock.
Sherman Harris---	6 miles southwest of Manchester.	121	101	----------	----	Do
----------	NE.¼ SE.¼ sec. 19	185	180	----------	----	High knoll; nearly all blue clay to rock.
----------	NE. ¼ SE. ¼ sec. 6	120	118	----------	----	
T. 88 N., R. 4 W. (Delhi).						
----------	NE. ¼ sec. 18----	125	65			
----------	SE. ¼ NE. ¼ sec. 19	185	----	----------	165	
----------	NW. ¼ SW.¼ sec.29	204	50	----------	----	
----------	NE. ¼ SW. ¼ sec. 31	220	100	----------	200	
----------	NW. ¼ NW.¼ sec.22	65	35	----------	----	
----------	SE. ¼ NW.¼ sec. 22	165	100	----------	----	
----------	SE. ¼ SE. ¼ sec. 14	214	100+	----------	----	
----------	S. ½ sec. 14----	150	140	----------	----	
----------	W. ½ sec. 13----	168	15	----------	148	
----------	SE. ¼ NW. ¼ sec. 24	225	40	----------	150	
George Morris----	E. ½ sec. 23----	141	46	----------	----	Bottom of ravine. Drift or alluvium, 46; dolomite (Niagaran), 75; "shell rock" described also as a "blue clay." (Maquoketa).

Typical wells of Delaware County—Continued

Owner	Location	Depth	Depth to rock	Source of Supply	Head below curb	Remarks (Log given in feet)
		Feet	Feet		Feet	
T. 88 N., R. 3 W. (North Fork)						
Mrs. Georgian	Rockville	80	------	Sand and gravel	------	Maquoketa bottoms. All sand and gravel.
Frank Kerns	2½ miles south of Dyersville.	160	12	------	------	Surface deposits, 12; limestone, 100; Maquoketa shale, 48.
—— Harris	2 miles south of Dyersville.	130	10	Limestone	------	Surface deposits, 10; limestone, 119; shale, 1.
N. Felters	2 miles northwest of Worthington.	320	90	do	------	Ridge. Drift, mostly blue clay, 90; limestone, 70; shale, 150; limestone, 10.
T. 89 N., R. 5 W. (Delaware)						
West Side School	Manchester	105	101	------	------	All blue clay to rock.
------	SW. ¼ NE. ¼ sec. 23	75	50	Limestone	------	Blue clay to rock.
School well	Manchester	302	104	------	------	Sand to rock; Maquoketa shale struck at 220 feet from surface; ends in shale.
------	SW. ¼ NW. ¼ sec.15	61	60	Sand	------	Sand to rock.
------	SE. ¼ SE. ¼ sec. 31	92	90	------	------	All blue clay to rock; on low ground; would overflow years ago in wet seasons.
------	Center of sec. 22	160	------	Gravel	------	
T. 89 N., R. 6 W. (Coffins Grove)						
------	SE. ¼ SE. ¼ sec. 21	110	102			
------	Center of sec. 21	80	72	------	------	
------	SE. ¼ SE. ¼ sec. 15	160	130	------	------	Ravine.
------	SW.¼ SE.¼ sec. 3	130	122	Limestone	------	Till to rock; a few streaks of quicksand.
------	NE.¼ SE.¼ sec. 4	120	90	------	------	Sand to thin clay, overlying rock; 1 sand well in locality.
------	NW.¼ NW.¼ sec. 30	132	130	Limestone	------	Clays, 90; shell rock, 10; solid rock, 20.
Charles Thorpe	9 miles west of Manchester.	140	------	Gravel	80	All blue clay to gravel.
Do	8 miles northwest of Manchester.	120	100	Limestone	------	
T. 89 N., R. 4 W. (Oneida).						
D. B. Bushnell	5 miles east of Manchester.	137	20	------	------	
T. 89 N., R. 3 W. (Bremen).						
------	1½ miles northeast of Earlville.	100+	------	Sand	------	Nearly all sand.
Henry Leschy	2½ miles southwest of Petersburg.	100+	------	Gravel	------	All sand and gravel.
—— Groffman	5 miles west of Dyersville.	99	------	Sand	------	Flowing well from sand under blue till.
—— Nachmann	do	119	------	do	------	Do
Henry Goertz	4 miles west of Dyersville.	85	------	do	------	High prairie; nearly all blue till.

Typical wells of Delaware County—Continued

Owner	Location	Depth	Depth to rock	Source of Supply	Head below curb	Remarks (Log given in feet)
		Feet	Feet		Feet	
Henry Lichtenberg	3½ miles northwest of Dyersville.	206	25	Limestone	126	High ground. Drift, 25; limestone, 181.
T. 90 N., R. 4 W. (Elk).						
A. B. Holbert	Greeley	265	60 105			Diameter, 6 inches.
T. 90 N., R. 3 W. (Colony).						
	Sec. 19	206		Sand		Ends in sand under heavy pebbly blue till
T. 90 N., R. 6 W. (Richland).						
Hugh Middleton	Near Strawberry Point.	265	65	Limestone		Drift, 65; limestone, 200.
—— Wood	NW. ¼ NE. ¼ sec. 26	130	100			Yellow clay, 8; blue clay, 92.
W. H. Sherwin	Near Forestville	131	30			
John Robinson	6 miles northwest of Manchester.	102	80			
Allix Schaufner	Schaufner	380	250			
	4 miles southeast of Strawberry Point.	230	230	Sand		Blue till, 215.

DUBUQUE COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

The topography of Dubuque county is composite. The eastern part, rising 600 feet and more above Mississippi river, which flows along its eastern border, was deeply gashed by the tributaries of the master river during the long periods preceding the glacial epoch, and the hills and valleys thus developed have been accented by erosion since that time. The western part of the county, because of distance from the main channels of erosion, was perhaps not so deeply and thoroughly dissected in preglacial time, and it has been blanketed with sheets of glacial stony clays deposited by successive ice sheets from the northwest. Its valleys have thus been partly or wholly filled and the sharp erosion profiles characteristic of the eastern driftless portion of the county have been blurred or quite obliterated.

The youngest drift present, the Iowan, forms two long lobes, one occupying the summit of the ridge reaching from Dyersville to Epworth, the other stretching from Worthington southeastward down John creek valley. These are areas of gently undulating prairie with a local relief on the more level portions of not more than forty or sixty feet in a square mile.

The remainder of the western and southern part of the county is occupied by older drift, the Kansan. Here the relief depends on two factors—the degree to which the preglacial rock-cut valleys were filled with drift, and the degree to which the drift has been removed by streams since its deposition. The time since the deposit of the Kansan drift has been long enough to permit a well-marked and fully developed drainage system to be initiated or restored. Streamways are incised below the upland crests to a depth of 150 feet about New Vienna and to more than 200 feet at Mellary. So broad, however, are the valleys that the local relief in places may not exceed 80 or 100 feet in a square mile.

The Kansan drift extends as far east as Bankston and Centralia and southeast to the Jackson county line. It reaches the edge of the main body of upland underlain by the Niagaran dolomite, but fails to follow out upon the long spurs which render the escarpment of this upland so strongly digitate. The remainder of the county lies in the driftless area.

In this area broad flat-floored valleys have been opened by the larger streams, such as the Little Maquoketa. It may be noted that adjacent to the Mississippi there has been developed a wide upland, now maturely dissected, standing about 240 feet above the river and about the same distance below the Niagaran upland to the west. This upland is underlain by the Maquoketa shale, and upon it are located the towns of Asbury, Julian, Ricardsville, and Key West. The origin of the upland, which is wholly comparable to that developed on the Saint Peter along Upper Iowa river in Allamakee county, need not here be discussed. Whether it is due to cliff recession of the overlying Niagaran or is a peneplain uplifted and dissected it is of special importance in the water supply of the county.

GEOLOGY.

The following geologic formations are present in Dubuque county:

Quaternary:
- Alluvium.
- Loess.
- Iowan drift.
- Kansan drift.
- Aftonian soil.
- Nebraskan drift.

Silurian:
- Niagaran dolomite.

Ordovician:
- Maquoketa shale.
- Galena dolomite.
- Decorah shale.
- Platteville limestone.
- Saint Peter sandstone.

Prairie du Chien stage.
- Shakopee dolomite.
- New Richmond sandstone.
- Oneota dolomite.

Cambrian:
- Jordan sandstone.
- Saint Lawrence formation.
- Dresbach sandstone and earlier Cambrian strata.

The following hypothetical geologic section is based on the scanty and in places conflicting data supplied by the records of the deep wells of the city of Dubuque. (See Pl. VI.) The thickness of the Galena dolomite is obtained by measurement of its outcrop.

General geologic section at Dubuque.

	Thickness	Elevation of stratum
Galena dolomite to Platteville limestone:	Feet	Feet
Dolomite	237	+550
Limestone, bituminous shale, green shale	46	+504
Saint Peter sandstone:		
White sandstone, water bearing	58	+446
Prairie du Chien stage:		
Dolomites (Shakopee and Oneota), arenaceous in places, New Richmond sandstone perhaps at 876 feet, with some shaly beds	310	+136
Jordan sandstone:		
Sandstone, water bearing	95	+41
Saint Lawrence formation:		
Dolomites and shales; dolomites to sea level, shales, red marls, arenaceous and glauconiferous	179	−138
Dresbach sandstone:		
Sandstone, water bearing	221	−359
Unnamed Cambrian strata:		
Shales	121	−480
Sandstone, water bearing above	768	−1,248

The lowest formation exposed to view in the county, the Saint Peter sandstone, outcrops at several places near Spechts Ferry at the base of the bluffs bordering the Mississippi. In these places the normally loose white sandstone has been discolored and hardened by iron compounds leached from the rocks above. The drill, however, everywhere throughout the county finds the Saint Peter of its normal aspect—a soft friable sandstone of round clear grains of quartz.

The Platteville limestone overlies the Saint Peter and appears along the Mississippi as far south as Eagle Point, Dubuque. It consists of a basal shale (the Glenwood shale of the Iowa State Survey), overlain by limestones, some magnesian and some fossiliferous, blue and brittle, and cut by the drill into flaky chips. Bituminous brown shales may be interbedded with these limestones. Above the Platteville lies the Decorah shale, a highly fossiliferous plastic shale with lenses of limestone. The Decorah is succeeded in ascending order by the Galena dolomite, which as now defined includes all from the summit of the Decorah shale to the base of the Maquoketa shale. The entire body of the Galena may be dolomitized, as at Dubuque, or more or less of the body of rock may have escaped the process and remain in its original nonmagnesian or slightly magnesian state. Where dolomitized, the Galena is porous and cavernous. It is the lead-bearing rock at Dubuque, where its thickness reaches 237 feet. The Galena forms the bedrock over a considerable area in the immediate vicinity of the streams in the northwestern part of the county.

The Maquoketa consists in Dubuque county of 50 feet of friable shale with earthy limestones overlain by 150 feet of plastic blue shale. These impervious and dry rocks immediately underlie a large upland area in the eastern part of the county (p. 373). The shale is well known to drillers throughout the county. The progress of the drill is retarded in this formation by the fact that the drill hole must be washed out every two or two and one-half feet.

The uppermost geologic formation of the county and the most extensive in its outcrops is the Niagaran—a buff dolomite, in many places cherty, especially toward the base. It underlies the superficial deposits west and south of the conspicuous, sinuous line of cliffs of the Niagaran escarpment. As rock, the Niagaran closely resembles the dolomitized Galena and could hardly be told from it by the cuttings of the drill, although the Niagaran tends in color to blue-grays and to lighter buffs rather than to the darker buff of the Galena. The two formations are readily distinguished by their surface distribution and by the thick shale which parts them.

The drift sheets of the county are three. The oldest, or Nebraskan, is separated from the overlying Kansan by the interglacial Aftonian deposits, consisting of old forest beds representing an interval during which soils accumulated and forests grew on the older glacial ground moraine. Both the Kansan and Nebraskan drift sheets are tough blue stony clays(although superficially the Kansan is deeply reddened by long weathering. The lobes occupied by the thin sheet of Iowan drift have already been mentioned. (p. 372).

The loess, a yellow or ashen silt or dust deposit, mantles everywhere the eroded surface of the Kansan and the driftless area.

UNDERGROUND WATER.

SOURCES AND DISTRIBUTION.

With the wide range of formations exposed in Dubuque county the number of horizons at which ground water may be found is exceptionally large.

The drift water beds consist of different sands and gravels either separating different drift sheets, inclosed within the stony clay of an individual drift sheet, or resting immediately on bedrock. The upper interglacial gravels have long since been left behind by the gradual lowering of the ground water since the country was opened to cultivation. Drillers state that no water is now found between the yellow and the blue clays, and the seepages at the base of the loess have also gone dry. Only the basal sands of the drift supply stock wells at present, and these sands carry little water except where the drift is of considerable thickness. Drift wells drawing their water from this source are naturally most numerous on the slightly dissected Iowan drift plains. Thus about Worthington wells are commonly from 100 to 120 feet deep and "just about reach rock;" on the Farley lobe of the Iowan drift wells are reported as supplied from gravels 135 and 160 feet below the surface and covered chiefly by blue till. The depth of wells in drift is affected by the varying thickness of this glacial deposit, due in part to the preglacial relief of the country. A strip of "deep country" is reported in Taylor township, extending from southeast to northwest and running out northwest of Epworth, the drift here being 100 feet and more in thickness. West of Bankton rock may be covered with 70 feet of drift within 1,000 feet of its outcrops. In Epworth rock is reached at 35 feet in places on the low ridge at the west end of town, whereas at the east end the drift is 135 feet deep. In places, as on the ridges about Farley drillers report a stiff unctuous clay five or six feet thick, resting on rock. This is probably the red residual clay to be looked for on ancient weathered limestone surfaces, and to the driller it is a far less desirable formation than the water-carrying glacial gravels that in many places rest directly on the rock.

The Niagaran is the chief water bed of the county in the southern and western parts. The well records give no section of the formation as more than 135 feet, although the measured outcrops give a thickness of somewhat more than 200 feet. No special horizons within this thick body of dolomite have been noted at which water can be expected. Where local conditions permit its ready drainage, as on the long spurs along its border, water will be found, if at all, only at its base. Back from the margin, where, owing to lack of dissection, ground water stands high and the larger part of the dolomite is waterlogged, water may be found wherever the drill encounters a crevice or an especially porous layer.

Even far within the border of the Niagaran the drill may occasionally fail to strike such a crevice or porous bed and may reach the base of the formation and enter the Maquoketa shale without having found a water supply. If the well is continued it should be with the full understanding that this shale is dry throughout its thickness of 200 feet and more, and it may be necessary to drill some distance into the Galena before finding a good water bed. Wells in the Niagaran are reported which thus reached a total depth of 400 and even of 500 feet.

On the ancient weather terrace or peneplain developed on the Maquoketa shale about Dubuque, wells do not find water until they reach the basal portion of the Maquoketa, consisting of earthy non-plastic layers, or the upper thin-layered beds of the Galena.

In the northeastern parts of the county water is found in the Galena and Platteville at depths depending on the height to which these bodies of dolomite and limestone are locally waterlogged and on the success of the drill in striking a water vein.

At Linwood, Dubuque, a well which entered the Galena at 40 feet found water within 145 feet of the surface of the ground. Another well at Linwood in the Roman Catholic cemetery was sunk to 312 feet, some water being found at 190 feet. On the bluffs at Dubuque the ground-water level stands about 150 feet below the surface, lowering, however, toward the river, as seen in the Fourteenth Street mine. In this area a number of wells, about 100 feet deep, are used for cesspools, the contents discharging freely into the ground water, from which house wells in the same district are supplied. Northeast of Sherrills Mound, an outlier of the Niagaran, wells run about 200 feet in depth, finding their supply in the Galena and Platteville.

The Saint Peter, the lowest water bed except those of the deep artesian wells of Dubuque, is tapped only near Mississippi river in the northeastern portion of the county. Thus, on the Peru bottoms the 160-foot well of William Cavanaugh (SW. 1/4 SW. 1/4 sec. 35, T. 90, R. 3 E.) struck light yellow water-bearing sandstone six or seven feet thick, beneath 154 feet of alluvial quicksand and gravel.

The alluvial deposits outside of the broad flood plains of the Mississippi are so small in extent that they hardly need mention. An interesting belt of country where water is obtained in river deposits is that of the Couler valley, which extends northwest from the city of Dubuque to Sageville. In this ancient abandoned river channel driven wells furnish sufficient water for household and ordinary farm uses. The deep well at the works of the Dubuque Malting Company shows that the alluvium in this valley is 117 feet thick. At Eagle Point, Dubuque, the well of Amos Bailey, on the flood-plain of the Mississippi, was sunk through 160 feet of alluvium before striking rock, the total depth of the well being 170 feet.

SPRINGS.

The two best-marked spring horizons in Dubuque county are at the summits of the Maquoketa shale and the Decorah shale. At both these horizons ground water is arrested in its descent by an impervious floor of shale and finds way to open air wherever the basal strata of the limestones are trenched by the channels of surface drainage. The large quantity of water gathered and the easy solubility of the limestones, which permits the opening of passageways of considerable size, give rise to copious springs. Along each of these horizons the spring may not mark the exact line of junction of two formations; it may lead out through talus cloaking the hillside to issue from this loose rock waste at some lower level than the summit of the shale; or it may issue at some higher level than the shale, owing to the devious windings of the subterranean passages dissolved in limestone.

Of less importance is the Niagaran dolomite. Springs are found issuing from its crevices along the North Fork of the Maquoketa.

These water beds are cut by the valleys of the streams in almost every section of the northeastern part of the county, and springs are correspondingly numerous. The perennial flow of the Little Maquoketa is due to its supply by springs issuing from the summit of the Maquoketa shale, which takes its name from its outcrops along this stream. On the other hand, the next stream to the south, Catfish creek, which drains the plain developed in the Maquoketa shale, goes dry each year for lack of springs within its catchment area, although this is large enough to give rise to torrential and destructive floods from the run-off of heavy rains.

Among the more important of the springs of the county may be mentioned that at Washington Mills, which issues at the exact contact between the Niagaran and the Maquoketa; a large spring near Rochester; one in section 4, Georgetown township; and the springs issuing along the bluffs of the Mississippi which supply the villages of Spechts Ferry and Waupeton.

CITY AND VILLAGE SUPPLIES.

Cascade.—Cascade (population, 1,268) pumps water from a spring issuing from the Niagaran dolomite to a tank with a capacity of 20,000 gallons. The amount used daily is 70,000 gallons. The gravity domestic pressure is 56 pounds and the fire pressure 100 pounds. The system comprises one mile of mains, 52 taps, and 15 fire hydrants.

Dubuque.—The city of Dubuque (population 38,494) is supplied by artesian wells (Pl. VI), from which 4,000,000 gallons daily are pumped to a reservoir and distributed under gravity pressure of 45 pounds. There are 63 miles of mains, 363 fire hydrants, and 3,300 taps.

At Dubuque the chief water beds are the Dresbach and earlier Cambrian sandstones. The Saint Peter sandstone, Prairie du Chien stage, and Jordan sandstone are of minor importance. Wells about 1,000 feet in depth tap all reservoirs except those below the Cambrian shale underlying the Dresbach sandstone. and wells 1,300 feet or more in depth reach the stores found in the Cambrian sandstone underlying this shale. If the conditions reported at the deepest well of the Linwood Cemetery prevail throughout the field, no water need be expected below 1,650 feet.

The head of the water of the lower sandstone of the Cambrian just described seems somewhat higher than that of the Dresbach sandstone, as seen in the well of the Key City Gas Company, where the two waters are kept apart.

PERMANENCE.

The first deep wells drilled at Dubuque were put down to about 1,000 feet, tapping the Jordan and the Dresbach sandstones. They had a static level of more than 700 feet, heading a little more than 100 feet above the lower ground of the city. Thus the well of the Butchers' Association is reported to have headed at 740, the Julien House well at 724, and the well of the Steam Heating Company, drilled in 1884, at 704 feet above sea level. The enormous discharge of the 10-inch well drilled in 1888 by the waterworks company at Eighth Street reduced very generally the head of the other wells, and later wells from 900 to 1,300 feet in depth showed a distinctly lower static level (Schmidt well, 645 feet above sea level; Chicago, Milwaukee & St. Paul Ry. well, 683 feet above sea level). The latest well of this class, that of the gas company, had a static level of 667 feet above sea level.

Of the deeper wells tapping the lower sandstone of the Cambrian the initial head of the Linwood Cemetery well was 742 feet above sea level, but in 1900 this had declined to 661, and the Sixth Avenue well at Eagle Point showed an initial head of but 647 feet.

The use of compressed air in several wells has caused a sudden loss of pressure in neighboring wells, and this lowering of static level may be expected to widen in area and increase in amount.

In 1905 several old wells still held their waters up to from 630 to 645 feet above sea level, and the Julien House well and the gas company well showed heads respectively of 685 and 667 feet above sea level. In 1908 the wells reporting in response to letters of inquiry showed heads not exceeding 625 feet above sea level, except in one or two doubtful cases.

The early failure of some of the wells points to defective or deteriorated casings, but the general loss of head, a loss in several wells sudden and coincident with the completion of new wells of great capacity on low ground or with the installation of air lifts in other wells, finds its cause in a general lowering of static level due to overdraft. For this condition there is no remedy except the partial one of restriction of outflow so far as possible. Wells in plants not in operation should be closed, and lateral escape of waters through defective casing and through channels opened in the rock where the well is not cased should be prevented by keeping all wells effectively cased to the chief aquifers.

WELLS.

The Butchers' Association well has a depth of 1,000 feet and a diameter of 8 inches to the bottom; it is cased to 300 feet. The curb is 607 feet above sea level. The original head was 133 feet above the curb and the head in 1896 was 41 feet above the curb. The original flow was 580 gallons a minute. No record of the present head and discharge has been obtained. Water was first tapped at a depth of 600 feet and gradually increased to the bottom. The temperature is 56.5° F. The well was completed in 1887 by J. P. Miller & Company of Chicago.

The Lorimer House well has a depth of 1,057 feet and a diameter of 5 inches. The curb is 652 feet above sea level. The original head was 57 feet above the curb and the head in 1896 approximately at curb. The original flow of 400 gallons a minute had ceased in 1906. The well was drilled by J. P. Miller & Company of Chicago. It has not been in use since 1892.

The Julien House well had an original depth of 896 feet but was deepened in 1898 to 1,660 feet. Its diameters are 12, 6, and 5 inches, cased originally to 212 feet. The curb is 615 feet above sea level. The original head was 109 feet above curb; head in 1896, 97 feet above the curb; head in 1905, 70 feet above the curb. The original flow was 480 gallons a minute. The well was drilled in 1872 by J. P. Miller & Company of Chicago.

Before the well was deepened the flow had ceased. The sinking of the city wells had no influence on the flow, but the first night that the air compressor was set working in the city well, about 11 blocks away, the Julien House well discharged about two bushels of sand.

Driller's log of Julien House well at Dubuque.

	Thickness	Depth
	Feet	Feet
Loose material	210	210
Sandstone	160	370
Marl	66	436
Sand, marl, and limestone mixed	50	486
Sandstone	60	546
Limestone	105	651
Marl, red	40	691
Shale, sandy	46	737
Marl, red	7	744
Sandstone	141	885

The Linwood Cemetery well No. 1 has a depth of 1,765 feet. Its curb is approximately 776 feet above sea level and its original head was 23 feet below the curb. The well is now pumped with a cylinder 200 feet below the curb.

The Linwood Cemetery well No. 2 has a depth of 1,954 feet and a diameter of 8 inches to 1,000 feet and 6 inches to bottom; casing to 1,025 feet. The curb is 706 feet above sea level. The original head was 36 feet above curb; head in 1896, 1(?) foot above curb; head in 1900, 45 feet below curb. The original flow was 40 gallons a minute; flow in 1896, 20 gallons a minute; well now pumped. Water from a depth of 100 feet rose nearly to the surface. The first rock flow was at about 1,250 feet and gradually increased until drill reached a depth of 1,650 feet, below which no water was found. The well was completed in 1891 by J. P. Miller & Company of Chicago.

This well is sometimes obstructed by a "fibrous sediment" which may be Crenothrix and which is removed by churning an iron rod in the tube. At times this treatment has doubled the diminished flow.

The J. Cushing factory well has a depth of 965 feet and a diameter of 7 inches to 60 feet, 5 inches to 190 feet, and 4 inches to bottom; cased to bottom. The curb is 642 feet above sea level. The original head was 31 feet above the curb and the head in 1896 at curb. Water comes from 600 feet and lower. The temperature is 60° F. The well was completed in 1888 by J. P. Miller & Company of Chicago.

The Packing & Provision Company's well has a depth of 955 feet and a diameter of 8 and 6 inches; cased to 200 feet. The curb is 607 feet above sea level. The original head was 55 feet above the curb; head in 1896, 50 feet above curb; head in 1905, 23 feet above curb. The original flow was 340 gallons a minute, the present tested capacity, with pump cylinder 16 feet above curb, is 90 gallons a minute. The well was completed in 1889 by J. P. Miller & Company, of Chicago.

The Consumers' Steam Heating Company's well has a depth of 802 feet and a diameter of 4 inches. The curb is 617 feet above sea level. The original head was 87 feet above curb and the head in 1896 at curb. The original flow of 260 gallons a minute had ceased in 1896. The water comes from depths of 353, 480, and 780 feet. The well was completed in 1884 by J. P. Miller & Company, of Chicago.

Driller's log of Steam Heating Company's well at Dubuque.

	Thickness	Depth
	Feet	Feet
Depth to rock (alluvium)	165	165
Sandstone	6	171
Sand and shale	5	176
Limestone, white	128	304
Limestone, gray	42	346
Sand and lime (inspection of the tube shows that this includes a cherty limestone, perhaps arenaceous, a gray limestone, and lowest a brown cherty	135	481
Sandstone, brown	20	501
Marl, yellow	3	504
Sand and lime	10	514
Sandstone	62	576
Lime	18	594
Marl, red	87	687
Shale, sandy, green	64	745
Marl, red	10	755
Sandstone, cream yellow	47	802

The Schmidt brewery well (W. Weiss Beer Company) has a depth of 886 feet and a diameter of 8 to 6 inches; 8-inch casing to 80 feet, 5-inch casing to 120 feet. The curb is 630 feet above sea level. The head in 1896 was 15 feet above curb; the present head is below curb; water rises nights and Sundays. The well now pumps 35 gallons a minute with the cylinder set 16 feet below curb. The water comes from depths of 500 feet, 700 to 800 feet (main flow), and below. The well was completed in 1891 by J. Bicksler, of Dubuque.

Record of strata in Schmidt brewery well at Dubuque.

	Depth in feet
Sand and gravel	25
Sand, yellow	30
Sand, reddish	56
Dolomite, buff; aspect of Galena	60-65
Limestone, dark bluish gray and buff	80
Limestone, magnesian, or dolomite; dark drab, mottled with lighter color; in small angular fragments, residue after solution large; argillaceous, siliceous, and pyritiferous; three samples	100-114
Sandstone, white, moderately coarse; grains rounded, smooth, and comparatively uniform in size	126
Dolomite, light yellow-gray, nearly white, with much sand in drillings	140
Sandstone, as at 126 feet	156
Dolomite; drillings chiefly chert	189
Dolomite, gray, highly cherty at 250 feet	210-250
Sandstone, white, many grains faceted; some dolomite chips in drillings	254
Dolomite, light buff, in fine sand, with chert and quartz sand	258
Sandstone, white, with calcareous cement	267
No samples	267-426
Dolomite, buff, cherty	426
Dolomite, brown; chippings splintery; mostly of flint with some of drusy quartz	430

Sandstone, cream yellow, moderately fine, calciferous as shown by dolomite and cherty material in drillings; three samples	465-474
Dolomite, buff; in fine sand, with some quartz sand	478
Sandstone, light reddish yellow, fine, calciferous	535
Dolomite, in fine buff sand and gray chips	581-584½
Shale, highly arenaceous, glauconiferous; in chips which pulverize into reddish yellow powder at 632 feet and reddish brown at 636 feet, quartzose material, microscopic and angular	632-636
Dolomite, highly arenaceous, glauconiferous; in fine brown angular sand at 724 feet and in coarser sand at 726 feet	724-726
Sandstone, yellow; grains moderately fine, the larger rounded and smoothed	730
Sandstone, pure, white; grains rounded, moderately fine	841

The Bank and Insurance Building well had a depth of 973 feet, but was deepened in 1900 to 1,380 feet. Its diameter is 8 to 4½ inches. The casing extends to 150 feet, and also covers 50 feet of shales below 200 feet. The curb is 638 feet above sea level. The original head was 10 feet above the curb; the present head is 3 feet above curb (water pumped to tank on roof). The original flow was 120 gallons a minute, which increased in 1900, after deepening, to 125 gallons a minute. The first flow was at a depth of about 900 feet. Temperature, 61° F. Date of completion, 1894; drillers, J. P. Miller & Company, Chicago.

The E. Hemmi dairy well has a depth of 973 feet. The curb is 627 feet above sea level. It was completed in 1895 (?).

This well stopped flowing on the starting of the air compressors of the malting company. It is now pumped by a windmill.

The Dubuque Brewing & Malting Company's well had a depth of 999 feet, but was deepened in 1904 to 1,165 feet. Its diameter is 8 to 6 inches. The curb is 624 feet above sea level. The well was completed in 1895 by J. Bicksler, of Dubuque, and was deepened and recased to 450 feet in 1904 by J. P. Miller & Company, of Chicago. No definite facts are obtainable as to head and discharge. The original flow was received in a reservoir from which it was pumped throughout the brewery. The flow ceased when the air compressors of the city wells were in use, and an air compressor was installed to pump the well, whose capacity was estimated at 150 gallons a minute. The repairs made by deepening and recasing the well in 1904 are reported as having been very beneficial, but the increase in flow or pressure is not stated. In 1908 the head was six inches above the curb, the flow being increased by the use of the air compressor.

Driller's log of Dubuque Malting and Brewing Company's well.

	Thickness	Depth
	Feet	Feet
Surface material	117	117
Limestone	33	150
Sandstone	75	225
Limestone	225	450
No record	533	983
Shale	45	1,028
Marl, red	2	1,030
Sandstone	135	1,165

The Key City Gas Company's well has a depth of 1,310 feet and a diameter of 10 inches to bedrock (116 feet), 8 inches to 562 feet, 6¼ inches to 1,070 feet, and 5 inches to the bottom; casing, 10 inches to 116 feet and 4 inches from curb to 1,118 feet. The curb is 619 feet above sea level. The original head was 48 feet above curb; head in 1905, 48 feet above curb. The original flow was 400 gallons a minute. Water comes from depths of 1,000, 1,118 and 1,310 feet. Temperature, 60° F. The well was completed in 1900 by J. P. Miller & Company, of Chicago. The waters of the higher water beds rise through the outer casing and those of the lower through the inner. The lower waters have the higher head, but the difference is variously reported. It is stated that on the completion of the well the flow of other wells in the city was diminished and some of the shallower wells ceased to flow. In 1905 the two flows had become mingled through corrosion of casing.

Driller's log of Key City Gas Company's well at Dubuque.

	Thickness	Depth
	Feet	Feet
Surface material	67	67
Limestone, shelly	49	116
Limestone or shale	34	150
Shale, sandy	320	470
Shale, red, and caving rock	75	545
Limestone	100	645
Shale	45	690
Sandstone	295	985
Shale, sandy	115	1,100
Rock, hard and soft streaks	210	1,310

The Chicago, Milwaukee & St. Paul Railway wells are two in number, each with a depth of 1,263 feet. The curbs are 607 feet above sea level. The original heads were 76 feet above curb; heads in 1905, 28 feet above curb. The well No. 1 was completed in 1898; it flowed 60 gallons a minute.

City well No. 1, Eighth and Pine Streets, has a depth of 1,310 feet and a diameter of 10 inches; casing, 400 feet. The curb is 607 feet above sea level. The original head was 46 feet above the curb; head in 1905, 23 feet above curb; head in 1908, 3 feet above curb. The original flow is unknown, but the flow in 1908 was 100 gallons a minute. The water came from depths of 500 and 1,310 feet. Date of completion, 1888.

The Eagle Point north city well has a depth of 1,308 feet and a diameter of 12 inches; 12-inch casing to 400 feet. The curb is 625 feet above sea level. The original head was 24 feet above curb, and the head in 1905, 20 feet above curb. The flow in 1905 was 300 gallons a minute; flow in 1908, 230 gallons a minute; capacity under air compressor acting at 300 feet in depth, 805 gallons a minute. The first flow came from 800 feet. The well was completed in 1899 at a cost of $2,600.

The Eagle Point south city well has a depth of 1,306 feet and a diameter of 12 inches to 900 feet, 8 inches to bottom; casing, 8 inches to 1,000 feet. The flow in 1905 was 265 gallons per minute, and in 1908, 120 gallons a minute; capacity under the air compressor, 290 gallons a minute. The head was the same as that of the north well. Date of completion, 1899.

The Eagle Point Sixth Avenue city well has a depth of 1,927 (or 1,908) feet and a diameter of 4 inches; 4-inch casing to 450 feet. The original head was 22 feet above curb; head in 1905, 11 feet above curb. The original flow was 135 gallons a minute. Temperature 61° F. The well was completed in 1900.

The use of the air compressor in the north well stops the flow of the south well; in 1905 its use in the north and south wells reduced the flow in the Sixth Avenue well to one-third its normal discharge; the effect on the distant Eighth Street well is said to be slight.

An unpublished log of the waterworks well at Galena, Illinois, is here presented for comparison with the logs of wells at Dubuque.

Driller's log of well of waterworks at Galena, Illinois.

	Thickness	Depth
	Feet	Feet
Surface material	65	65
Limestone	95	160
Sand, white, water, first flow (Saint Peter)	105	265
Marl, red	40	305
Sandstone, white, water	222	527
Limestone, sandy	80	607
Shale, sandy	28	635
Limestone, sandy	50	685
Sand, white, water	28	913
Sand and limestone	12	925
Sand, white, water	645	1,570

Dyersville.—The water system of Dyersville (population, 1,511), owned by the city, obtains its supply from a 5-inch drilled well, 384 feet deep, entering rock at a depth of 2 feet. Water heads 150 feet from the surface. The chief water bed is found at 136 feet in Niagaran dolomite. Water is pumped by gasoline engine to a tank, whence it is distributed under gravity pressure of 45 pounds through 1 1-6 miles of mains. There are 30 taps and 20 fire hydrants.

The Saint Peter sandstone should be struck at about 260 feet above sea level, or 681 feet below the surface, and the Jordan at about 150 feet below sea level or about 1,090 feet below the surface. A well sunk to 250 feet below sea level, that is, to about 1,100 feet from the surface, should give a supply ample for the town so long as the well is kept in good repair. The water from the deeper beds may be expected to stand about 150 feet below the curb, but the upper waters, which will be found in the Niagaran, Galena and Platteville limestones, will come much higher and increase the head. The cylinder of the pump should be placed low enough to draw on the deeper waters after the upper limestone waters, which will be less in amount, have been pumped off.

Minor supplies.—Information concerning the supplies of some of the smaller places is contained in the following table:

Village supplies in Dubuque County.

Village	Nature of Supply	Depth of Wells From—	Depth of Wells To—	Depth of Wells Common	Depth to water bed	Depth to rock	Head	Springs
		Feet	Feet	Feet	Feet	Feet	Feet	
Bernard	Wells	80	600	120	100	12		None.
Durango	Cisterns and wells	30	135	130			—20	Large and small.
Epworth								
Farley	Drilled wells	60	120			15		
Peosta	do	18	535	150		25	—15 —30	Small.
Spechts Ferry	Springs							
Placid		24	315	120	120	300 135	—16 —80	
Waupeton	Springs							
Sageville				100				
Worthington	Drilled and open wells.	30	60	60	60	25	—15 —30	Small.

WELL DATA.

The following table gives data of typical wells in Dubuque county:

Wells in Dubuque County.

Owner	Location	Depth	Depth to rock	Source of Supply	Head	Remarks (Log given in feet)
T. 88 N., R. 1 E. (Vernon).		Feet	Feet		Feet	
Mrs. King	NW. ¼ NE. ¼ sec. 13	135				High ground.
Peter Broessel	SW. ¼ SW. ¼ sec. 7	200			—160	
J. McMahon	SW. ¼ SE. ¼ sec. 12	400				Dolomite; Niagaran, 60; Maquoketa shale and Galena limestone, 340.
T. 89 N., R. 2 E. (Dubuque).						
P. Erschen	Centralia	220			—190	
A. Hollins	do	120			— 40	
T. 89 N., R. 1 W. (Iowa).						
	Tivoli, sec. 8	140	66	Limestone		Yellow clay, 10; blue clay, 56; limestone, 74.
	Bankston	175				Drift and Niagaran dolomite to Maquoketa shale, 175 feet.
Clement Meyer	SW. ¼ NE. ¼ sec. 33	160	13			Rather high ground.
L. H. Fangmann	NE. ¼ SW. ¼ sec. 8	160		Gravel		All sand to gravel.
C. Fangmann	NE. ¼ SE. ¼ sec. 8	208	70	Limestone		Yellow clay to rock.
	Kidder	86	20	On shale		Low ground near creek. Reddish sand and clay, 20; limestone, 20; shale, 46.
Keller	4 miles northwest of Epworth.	160				Ridge. Maquoketa shale penetrated, 60.

Wells in Dubuque County—Continued

Owner	Location	Depth	Depth to rock	Source of Supply	Head	Remarks (Log given in feet)
T. 88 N., R. 1 W. (Taylor).		Feet	Feet		Feet	
—— Bennett	1 mile north of Epworth.	112				Mostly sand; limestone, 5.
Geo. Freeman	4 miles southwest of Epworth.	155		On shale	— 95	Yellow clay, 80; blue clay, 60; limestone, 40; shale, 25.
Aug. Krogmann	SW. ¼ SE. ¼ sec. 7	500				High hill. Drift. 60; limestone, 100; shale, 340. No water.
Geo. Graham	1½ miles southeast of Graham.	450	66			Ridge. Yellow clay, 40; blue clay, 26; limestone, 110; shale (Maquoketa), 254; hard gray limestone, 12; shale, 8.
—— Harns	East end of Epworth.	187	135	Limestone		Drift, nearly all sand, 135; Niagaran dolomite, 52.
M. M. McDermott	1½ miles south of Epworth.	115		Gravel		Yellow clay, 20; blue clay, 87; gravel, 8.
Mr. Quirrin	Sec. 11	250	190			
N. Bradfield	Sec. 12	140	135		—100	Blue till from 40 to 135.
T. Smith	Sec. 22	83	65			Black drift into wood above rock.
J. Haly	Sec. 34	195	190			Mainly yellow till and sandy material to rock with some "black clay."
Geo. Banerich	SW. ¼ NE. ¼ sec. 31	220	85	Limestone		Drift, 85; Niagaran dolomite, 135.
T. 88 N., R. 1 W. (Dodge).						
	2 miles northwest of Farley.	135		Gravel		Nearly all blue clay to gravel.
—— Martin	1½ miles west of Farley.	160		do		Blue clay to water bed.
J. N. Crapp	Sec. 11	102	102		— 66	Mainly yellow till.
F. Funke	Sec. 9	154	117		— 54	67 feet of blue-black till on rock.
Aug. Coopman	2 miles south of Dyersville.	300	6			High ground. Drift, 6; Niagaran dolomite, 100; Maquoketa shale, 194; ends in shale.
Town	Worthington	56	30	Limestone	— 18	Diameter, 5¾ inches. Depth to water supply, 50.
T. 90 N., R. 1 W. (Concord).						
John Frietmann	NE. ¼ NE. ¼ sec. 16	164		Sand and gravel		Blue stony clay to water bed.
Nicholas Smith	SE. ¼ SE. ¼ sec. 32	200				Reached Maquoketa shale.
T. 88 N., R. 2 E. (Table Mound).						
C. Ehrsam	NW. ¼ sec. 18			Sand and gravel		Valley. Mostly soft quicksand; rock not reached.
T 89 N., R. 1 E. (Center)						
	Centralia	250				Drift and loess, 30; blue shale, 220.
H. Calahan	Sec. 7	416			—398	Altitude, 1,150 feet; 32 feet of drift.
	Sec. 7	112	60	do		Yellow and blue clay, 60; limestone, 52.
T. 89 N., R. 2 W. (New Wine).						
—— Mayberry	2½ miles northwest of Farley.	92	32	do	— 52	Yellow clay, 12; blue clay, 20; limestone, 60.

FAYETTE COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

Lying near the margin of the driftless area, Fayette county includes two types of topography, each of which exercises a certain control over the distribution of ground water. The northeastern part of the county—the area lying east and north of West Union and Fayette—is a land of hills, some of which are 400 feet high, carved by streams from an upland about 1,200 feet above sea level. Here the Kansan drift is thin and the topography of preglacial time is not effaced or even masked. Over the remainder of the county the preglacial hills and valleys have been deeply buried beneath drift, and the latest ice sheet to invade the region, the Iowan, has molded the surface to a gently undulating prairie. In this prairie region ground water stands high, feeding the streams of the shallow valleys with oozes along their banks; in the rugged country of the northeastern part ground water stands low and must be sought by wells at levels approximating those of the bases of the hills, where it issues in copious springs.

The divide between Volga and Turkey rivers reaches an elevation of 1,280 feet above sea level; the lowest valley floors descend to 775 feet above sea level. The two areas are roughly sketched in any road map of the county. In the dissected area the crooked highways follow around hill and up winding valley and along the sinuous ridge tops; on the prairie of the younger drift they adhere to the section lines undeviatingly.

The broad, flat valleys of the streams of the dissected area form a topographic type of special interest in this investigation. Their width, which commonly reaches a mile along Volga and Turkey rivers, is an expression of an advanced stage of development due not only to their great age, but also to the weak rock, the Maquoketa shale, in which they have been worn.

GEOLOGY.

Pleistocene drift deposits mantle the entire county. In the hilly northeastern part they are thin and almost negligible from the present viewpoint. Over the prairies of the county they are thick. The great bulk of the drift belongs to the earlier drift sheets, the Nebraskan and the Kansan. The Iowan drift forms a veneer on the older drift over about two-thirds of the county. Outside of the Iowan area the stony clays of the drift are mantled with a fine yellow silt called loess.

The well driller does not distinguish between these superficial deposits, nor is their discrimination easy in the contents of the slush bucket. Yet valuable data may be obtained by noting the depth at which the gritless yellow loess passes into the ashen loess beneath it or into the sands which in a few places underlie it, or into the brighter yellow stony clay of the weathered Kansan. The place and thickness of the sandbeds which locally intervene between the Kansan and Nebraskan should also be noted. At the same horizon (Aftonian) will be found in places old soils, deposits of peat, and forest beds, whose dark and ill-smelling products are recognized at once. The driller should also note the depth at which the weathered reddish or yellow Kansan passes into the blue unoxidized and tougher stony clay of the unweathered basal portion of that drift.

Several members of the Devonian system, differing lithologically one from another, are exposed in different places in the central and western parts of the county, as in the deep railway cut at Fayette, but their discrimination matters little in this investigation.

The Niagaran dolomite (Silurian) appears in the cliffs along the valleys of Turkey and Volga rivers and forms the bedrock in parts of Illyria, Dover, Auburn, Union and Westfield townships. Covered by heavy drift, it is supposed to underlie the southern townships. The rock is for the most part a buff dolomite, although beds of gray nonmagnesian limestone occur locally. The measured outcrops do not exceed 70 feet.

Because of its impervious shales, the Maquoketa (Ordovician) exerts a strong influence on the distribution of ground water. The formation includes a basal member nearly 100 feet thick, made up of shales and clayey limestones, a middle member about fifty feet thick composed of cherty magnesian limestones, and an upper member, a plastic bluish shale, whose thickness may reach 125 feet. These beds form the surface rock over Clermont and most of Dover townships, and over the northeastern part of Auburn township. They form the bedrock of the valley floor of the Volga to three miles north of Lima, of Turkey river to its junction with Crane creek, and of Otter creek to a point within two miles of West Union.

The 70 feet of the upper beds of the Galena (Ordovician) exposed in the county are nondolomitic limestones, light gray in color, and may be recognized by the driller by these characteristics, as well as by their position immediately beneath the easily determined base of the Maquoketa shale. They outcrop along the valley of Turkey river and its tributaries above Clermont.

UNDERGROUND WATER.

SOURCES AND DISTRIBUTION.

In the northeastern part of the county water is obtained chiefly in the bedrock. The drift is thin, and the loess seldom affords a large or permanent supply. Wells encounter, immediately above the rock, a stratum of residual flints several feet thick, but this stratum does not form a water bed, as the flints are set in impervious red residual clay. In Clermont and much of Pleasant Valley townships, where the Maquoketa shale forms the country rock, water may be found above the blue upper shale of that formation, but generally the drill must go to the limestones of the Middle Maquoketa, or even into the Galena and Platteville limestones underlying the heavy shales of the Lower Maquoketa. As the thickness of the Maquoketa is estimated at not less than 250 feet, it is not surprising that some of the deeper wells of the area are 400 feet deep.

On the high uplands of the northeastern townships, where the Niagaran dolomite forms the country rock, water is commonly found at moderate depths, but even here in a few wells the drill fails to strike water in the Niagaran, and wells are reported which go to the Middle Maquoketa. One west of Wadena passed through eighty feet of "sand rock" (Niagaran), 155 feet of "soapstone" (Upper Maquoketa), fifteen feet of "dark shale in chips," and thirty-two feet of limestone (Middle Maquoketa), finding water in the beds last named.

The wide valley floors of Turkey and Volga rivers form a distinct province where shallow wells tap the abundant water of alluvial sands and gravels.

In the remainder of the county the chief water beds are (1) sands and gravels of glacial origin, interbedded with stony clays or overlying the rock at different depths from the surface, and (2) Devonian and Silurian limestones. In the southeastern part of the county, in Fairfield, Smithfield, Putnam and Scott townships, water is found in the basal glacial gravels and in the Niagaran dolomite. Wells vary in depth with the thickness of the drift and with the depth in the Niagaran at which a water-bearing crevice or porous layer may be encountered.

The data at hand suggest that the drift ranges in thickness commonly from 70 to 150 feet. Near Scott, however, some wells find water in glacial sands resting on rock at a depth of 170 feet. Four miles west and one mile north of Arlington the same water-bearing sands lie in places about 200 feet from the surface. About four miles southwest of Arlington the average depth to rock is 150 feet, most wells here finding water on the rock or a few feet below the rock surface. Near Taylorsville some wells are sunk about sixty feet below the rock surface. On the high ridge north of Brush creek ground water in the limestone stands low and wells may need to go through 150 feet or more of rock before obtaining a supply.

In the southwestern townships the drift is of considerable thickness, although at Fairbank, Maynard and Randalia the rock approaches close to the surface or outcrops. In Oran and Fremont townships a common range of from 50 to 125 feet is indicated by our reports, wells seldom exceeding 150 feet in depth. At Westgate rock is reached at 80 feet and from Oelwein west to Little Wapsipinicon river wells footing in keel rock are said to range from 75 to 100 feet in depth. In Jefferson township the drift is thicker than in Oran, and wells which here find water in its basal sands or in the upper layers of the underlying rock commonly exceed 100 feet. At Oelwein on the hills house wells are about 145 feet deep and foot in rock, five feet being sufficient for reservoir and anchorage for casings. On the other hand, in the northwestern part of the city rock lies at thirty feet. At the Roman Catholic Church a well penetrated sand for sixty feet, whereas wells not 100 feet distant on either side struck rock within three feet of the surface. This narrow bed of sand runs half a mile southwest to Otter creek. The steepness of the rock walls of this buried channel is shown by the fact that at a house in the town the excavation for the cellar encountered rock at four feet, and a well five or six feet from the house wall penetrated sand for sixty feet.

In Harlan, Center and Banks townships wells find water in basal sands and gravels or immediately below the rock surface in the Devonian limestones. In Banks township the drift apparently runs deep and a thickness of 187 feet is reported at one locality. A short distance southeast of Randalia rock comes to the surface, though immediately at the village it is 90 feet below ground. About Maynard stock wells run to depths of from 40 to 100 feet, and are commonly drilled from five to ten feet in rock.

In the northwestern part of the county, which is comprised within the limits of the Iowan drift plain, the general conditions are the same as in the central and southwestern parts.

A few flowing wells from Pleistocene sands overlain by stony clays are reported from the county, but no provinces were found of sufficient importance to deserve investigation. These flows occur on low ground on a branch of Turkey river in Windsor township and at one or two points along Otter creek north of Oelwein, and on the Little Wapsipinicon.

SPRINGS.

Springs are numerous and many of them are copious in the northeastern part of the county along the valleys of Volga and Turkey rivers. A well-marked horizon occurs at the base of the Devonian, whence some large springs issue near Fayette. A still larger contribution of spring water is made by the rocks at the summit of the Maquoketa shale, for this impervious clay leads the ground water along its surface to open air wherever it is cut by streamways. At Wadena, on Turkey river, several springs issue on the hillsides, that of William Sargent being said to be 80 feet above the village. The water of one of these springs has been piped to the village, but no use has been made of them for power. In most of that part of the county covered with Iowan drift springs are few and small.

CITY AND VILLAGE SUPPLIES.

Arlington.—At Arlington (population, 678) water obtained from a well is pumped to a tank supplying pressures of 35 to 45 pounds. There are 2,400 feet of mains.

Fayette.—The public supply of Fayette (population, 1,112) is drawn from two eight-inch wells sixty-five feet deep, situated at the edge of town on the banks of Volga river. Their joint capacity is said to be 500,000 gallons a day, but a run of the pumps for not more than one and one-half hours a day is sufficient to meet present demands. Water stands fifteen feet below the surface, and is drawn down to seventeen and one-half feet by pumping a few minutes. The driller's log of the wells is as follows:

Log of well at Fayette.

	Thickness	Depth
	Feet	Feet
Soil and sand	30	30
Limestone, gray, hard	32	62
Sand rock	3	65

The sand rock in which the well ends is probably a coarse-grained magnesian limestone of the Niagaran; the limestone above corresponds with the Wapsipinicon limestone of the Devonian.

Water is distributed by direct pressure with domestic and fire pressures of 80 and 100 pounds respectively. There are 1,300 feet of mains and four fire hydrants.

The summit of the Niagaran dolomite at Fayette (elevation, 902 feet)is exposed along Volga river near the water line. The formation here is probably not more than 75 feet thick. A deep well would pass through the Niagaran into the Maquoketa shale, which is here about 200 feet thick and includes middle dolomitic beds that may carry water under a sufficient head to overflow at the surface. Still more water will probably be found in the 300 or 350 feet of the Galena and Platteville limestones, which underlie the Maquoketa. The Saint Peter sandstone should be reached about 625 feet below the surface. This estimate, based on the thickness of the formations, is believed to be more accurate than one based on the assumed uniform dip of the Saint Peter from Elkader to Sumner, which would bring the Saint Peter at Fayette about 470 feet below the surface.

The lower waters can not be expected to overflow, although they may rise near the surface. A well or wells sunk to the depth of about 675 feet will probably obtain sufficient water for a public supply, but the far more abundant stores of the Prairie du Chien and the Jordan may be reached by sinking the well 500 to 550 feet deeper.

Hawkeye.—At Hawkeye (population, 510) the public supply is pumped from a six-inch well to a tank 100 feet high and thence distributed through one mile of mains. There are nine fire hydrants. The well is 180 feet deep and is cased to rock, which it enters at 160 feet.

Oelwein.—The water supply for Oelwein (population, 6,028) is drawn from four wells, seven inches in diameter and 72 feet deep, connected and pumped with a vacuum pump. The capacity of the wells is somewhat less than 240 gallons a minute, as by pumping at this rate the water is lowered from a head of twelve feet below the surface to twenty-five feet below it, and the pumps begin to pound. The wells are located in the northeastern part of the city on a level with the railway station. Rock was entered at sixteen feet, and the main water bed was found in a seam at forty feet. The wells are adjacent to a deep well drilled for the city but never used. On testing the deep well with a cylinder set at 150 feet and pumping 250 gallons a minute, the water in the four wells was drawn down below the vacuum pump, the water in the deep well lowering in corresponding measure. The water in the deep well now rises and falls with that of the four wells, according as the vacuum pump is in action or at rest.

Water is distributed from a standpipe (capacity, 96,000 gallons) under a pressure of 60 to 75 pounds. There are eight miles of mains, 55 fire hydrants and more than 600 taps. The amount used daily exceeds 200,000 gallons.

The deep well was drilled for the city some years since by J. F. McCarthy of Minneapolis, but nothing can be learned about it except its depth, 1,000 feet, and its head, 15 feet below the curb. If the dip of the strata in this area is uniform between the nearest deep wells on either side of Oelwein, this well hardly more than reached the base of the Saint Peter sandstone. Whatever the supply of this well may have been, the capacity would doubtless have been increased by drilling deeper to the Jordan sandstone.

Westgate.—A supply used for fire protection at Westgate (population, 232) is obtained from a six-inch well, 98 feet deep. Rock is entered at 80 feet. The water bed is limestone at 85 feet, and the head is 30 feet below the curb. Water is pumped by gasoline engine to a tank 90 feet high, with a capacity of 600 barrels, and is thence distributed through 1,000 feet of mains. There are three fire hydrants.

West Union.—Four wells, 68 to 70 feet deep, situated at the base of the north bluff of Otter creek, supply West Union (population, 1,652) with about 100,000 gallons of water a day. The head of the water is sufficient to carry it over the curb, but overflow is prevented by closing three of the wells with cement. The wells are drilled almost wholly in limestone and are evidently closely related to the strong springs of this district, which issue from the lower beds of the Devonian limestone. The temperature of the water is about 51° F.

Water is pumped by a compound duplex steam pump to a standpipe, from which it is distributed with a domestic pressure of from 40 to 80 pounds through five miles of mains to 30 fire hydrants and 375 taps. The fire pressure is 110 pounds. It is improbable that the city will need to seek a deeper water supply for many years, but such a supply is obtainable in the Saint Peter sandstone, which should be found about 550 feet below the surface, or in the Jordan, whose base must be at about 1,150 feet. Water may be looked for in very moderate amounts in the Prairie du Chien stage and the Jordan sandstone. The water from these deep sandstones would probably stand 100 feet or more below the surface.

Minor supplies.—Information concerning the water supplies of the smaller villages is presented in the following table:

Village supplies in Fayette County.

Town	Nature of Supply	Depth of wells	Depth to water bed	Depth to rock	Head below curb	Volume of Springs
		Feet	Feet	Feet	Feet	
Alpha	Wells	20-40			16-30	
Brainard	Drilled wells and springs.	60				Small.
Clermont	Wells and springs	40-350	80-100			
Donnan	Bored and drilled wells.	20-120	120		15	Do.
Douglass	Wells and ponds	30-130	100	50	12-60	Large and small.
Eldorado	Drilled wells	40			20	Small.
Elgin	Wells			16-60	30	
Illyria	Drilled wells	90-312	138	40	70-175	Medium.
Lima	Wells	20-60	40-60		165-210	Small.
Maynard	do	80			20	
Randalia	Driven and bored wells.	12-125		90	20	
Waucoma	Wells	20-100				Do.
Westgate	Drilled wells	20-150	35-40	80	10	

WELL DATA.

The following table gives data of typical wells in Fayette county:

Typical wells of Fayette County.

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of Supply	Head above or below curb	Remarks (Log given in feet)
		Feet	Feet	Feet		Feet	
T. 92 N., R. 10 W. (Fremont).							
Fred Barle	5 miles southeast of Sumner.	145	139		Limestone	—115	
—— Dieperkoph	do	155	149				
Town	Westgate	98	80	85	Limestone	— 30	Used for fire protection only. Diameter, 6 in.
J. I. Minckler	2 miles southwest of Westgate.	60			Sand	+ 25	A little clay on top; then all sand to bottom. Diameter, 5 inches.
T. 91 N., R. 10 W. (Oran).							
G. L. Egan	NE. ¼ sec. 5	84	20	84	Limestone	+ 5	Valley of Little Wapsipinicon river. Supplies water for fishponds. Yields 15 gallons per minute from 5-inch pipe.

Typical wells in Fayette County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of Supply	Head above or below curb	Remarks (Log given in feet)
		Feet	Feet	Feet		Feet	
Peter Kanten	SE.¼ SE.¼ sec. 10.	55	45		Yellow limestone		
Edward Dundell	8 miles west and 1 mile north of Oelwein.	70	67		Limestone		All clay to rock.
Chicago Great Western Ry.	1 mile west of Oelwein.	120	116				Do.
Do	6 miles west of Oelwein.	64	60				
John Gerken	NW. ¼ sec. 9	100	48	40	Limestone	— 21	Diameter 6 in.
T. 91 N., R. 9 W. (Jefferson).							
— —Barr	SE. ¼ NE. ¼ sec. 23.	140	138				All blue clay to rock.
Oelwein town wells		145	140			— 60	Hill.
Do	Northwest part of town.		30				
Catholic Church	Oelwein	60			Sand		All sand; wells not 100 feet distant on either side strike rock in 3 feet.
Richard Swartz	SE. ¼ NE. ¼ sec. 8.	110			do		Clay, 60; sand, 20; clay.
Julius Tallman	8 miles northwest of Oelwein on Otter creek.	80		80	do		Overflows.
—— Platt	1 mile east of Oelwein.	102	100				
Creamery	At Craft's, east of Oelwein	70			Gravel		Blue clay, 50; sand, 20.
Frank Cragin	2 miles east of Oelwein.	40	38		Sand	— 20	Sand, 2; yellow clay, 10; sand, 26; limestone, 2.
T. 92 N., R. 9 W. (Harlan).							
—— Barnes	SW. ¼ NW. ¼ sec. 26.	120	118			— 60	Yellow clay, 10; blue clay, 50; quicksand, 25; dark clay and sand, 33; limestone, 2.
G. Beuzer	NE. ¼ NE. ¼ sec. 13.	40	32		Limestone	— 15	A good stock well on low ground.
—— McMaster	NW. ¼ NW. ¼ sec. 15.	80	70				
Do	1 mile north of preceding.	150	145				Clays, 60; quicksand, 15; brownish sand and clay, 50; quicksand, 20; limestone, 5.
	SW. ¼ SW. ¼ sec. 36.	130					Drift clays, 100; sand, 30.

Typical wells in Fayette County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head above or below curb	Remarks: (Log given in feet)
		Feet	Feet	Feet		Feet	
T. 91 N., R. 8 W. (Scott).							
Peter Kraft	NW. ¼ SW. ¼ sec. 14.	160	158	158	Limestone		Clay, yellow, 15; clay, blue, 105; dark soft muck without grit, 30; sand and gravel on rock.
—— Puffet	SE. ¼ SE. ¼ sec. 15.	175	175				High ground; yellow and blue clay, 155; sand, 20.
Frank Sherman	SW. ¼ SE. ¼ sec. 9.	180					Ends in rock.
	Sec. 15	171		170	Sand	— 36	Dry blue clay, 170; sand 1.
T. 92 N., R. 8 W. (Smithfield).							
Stephen Payne	NW. ¼ SW. ¼ sec. 20.	150	142				Clays, 80; yellow fine sand, 25; blue clay, 37; limestone, 8.
Jesse Paul	SW. ¼ SW. ¼ sec. 21.	130	127				Clays, 45; quicksand, 82; limestone, 3.
Charles Smith	SW. ¼ SW. ¼ sec. 22.	160	155				Clays, 40; sand, 115; limestone 5.
—— Turner	SE. ¼ SE. ¼ sec. 33.	150	148				Mostly clay to rock.
	SW. ¼ SW. ¼ sec. 34.	150			Sand		Clays 135; sand 15; Not strong.
W. B. Stevenson	SW. ¼ sec. 26	114	114		Sand and gravel on rock.		Diameter. 5 in.
J. J. Bogert	NE. ¼ sec. 27	218	160			— 90	58 feet of limestone. Diameter 6 inches.
	NE. ¼ NE. ¼ sec. 24.	100	20			— 60	Blue clay, 20; limestone and clay, 40; limestone, 40.
	SE. ¼ SE. ¼ sec. 21.	205	205	200	Sand	—100	Blue clay with thin streaks of sand, 4 inches thick, 200; white sand, 5. Level prairie.
H. H. Smith	4 miles southwest of Arlington.	265	200	260	Crevice in rock		Diameter, 5 in.
T. 91 N., R. 7 W. (Putnam).							
W. C. Gundlach	SE. ¼ sec. 31	73	70	70		— 2	Sand 10; gravel 3; blue clay, 57; rock, 3. Casing tapped so that well flows to tank on lower ground. Yields 2½ gallons per minute from 6-inch pipe.
T. 92 N., R. 7 W. (Fairfield).							
	NW. ¼ sec. 5	100	80		Limestone		Blue clay, 80; blue limestone, 20.
	NE. ¼ NW. ¼ sec. 5.	150	40		Crevice in limestone.	—146	Drift 40; limestone with crevice, 110.

Typical wells in Fayette County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head above or below curb	Remarks: (Log given in feet)
		Feet	Feet	Feet		Feet	
	NW. ¼ NW. ¼ sec. 6.	204					Yellow clay, 20; blue clay, 20; limestone, 60; "sandrock," 9.
George Clough	Sec. 22	153	90			— 65	Diameter, 5 in.
T. 93 N., R. 7 W. (Illyria).							
W. Flanegan	NE. ¼ NE. ¼ sec. 29.	312	30		Limestone	—247	Hill. Yellow clay, 30; "sandrock," 80; soapstone, 155; shale, dark in chips, 15; limestone, 32.
Alexander Peters	SW. ¼ NE. ¼ sec. 11.	140	40		Sandstone	—100	Yellow clay, 40; limestone, 60; "sandrock," 40. High ridge.
	NE. ¼ SW. ¼ sec. 25.	60	18				Volga river bottoms.
	NW. ¼ NE. ¼ sec 25.	75	50				Volga river bottoms, about 20 feet above river.
	NW. ¼ SW. ¼ sec. 4.	140	90		Limestone	—100	Yellow clay, 40; blue till, 50; limestone, 50.
T. 93 N., R. 8 W. (Westfield).							
J. Orr	SW. ¼ NE. ¼ sec. 21.	147					Ridge. No water obtained. Yellow clay 30; blue clay 50; limestone, 62; yellow, porous limestone,. 5.
	NE. ¼ NW. ¼ sec. 22.	212				—192	High ground. Yellow clay, 16; blue clay 44; rock and clay, 1; gray limestone, 149; "sandrock," 2.
Peter Graft	3 miles northeast of Fayette.	200	40	150			Yellow clay, 40; limestone, 150; soapstone, 10.
—— Bars	NW. ¼ SW. ¼ sec. 24.	288	30	280		—180	Drift, 30; limestone, 100; shale, blue, caving, 150; unknown, drillings washed out, 8.
—— Whitely	SE. ¼ SE. ¼ sec. 26.	205	80	200		—183	Yellow clay, 20; blue clay, 60 (at 45 feet old black soil, ill-smelling, 5); limestone, 120; "sandrock," 5.
	NE. ¼ NE. ¼ sec. 5.	65			"Sand-rock"		Drift 5; limestone 60. High level prairie.
	NW. ¼ NW. ¼ sec. 7.	100	80		Limestone	— 30	Blue clay 80; limestone, 20.
	NW. ¼ SW. ¼ sec. 19.	45			do		All limestone; plenty of water.
—— Dye	SW. ¼ SW. ¼ sec. 32.	160	50		do		Yellow clay, 15; blue clay, 35; limestone, 110.
—— Badger	Sec. 20	130					Drift, mainly yellow till, 30; rock, 100.

Typical wells in Fayette County—Continued

Owner	Location	Depth	Depth to rock	Depth to water supply	Source of supply	Head above or below curb	Remarks: (Log given in feet)
		Feet	Feet	Feet		Feet	
T. 93 N., R. 9 W. (Center).							
Clarence Moulton	NW. ¼ NW. ¼ sec. 20.	140	135		Limestone		Yellow clay, 10; blue clay, 70; quicksand, 55; limestone, 5.
T. 93 N., R. 10 W. (Banks).							
J. J. Cavlin	NE. ¼ NE. ¼ sec. 26.	190	187				Nearly all blue clay; a little sand on rock. Ridge.
T. 94 N., R. 7 W. (Pleasant Valley)							
	SE. ¼ SE. ¼ sec. 31.	135	80				Yellow and blue clay, 80; "sandrock," 55.
John Bracklin	SW. ¼ NE. ¼ sec. 18.	130	40	127	"Sandrock."	— 93	Yellow clay, 30; blue till, 10; residual flints, 12; limestone, 40; "sandrock" dark brown, soft, 38.
Canning Factory	Elgin	125	30		Limestone	— 45	Sand, 30; blue soft limestone, 10; "sandrock," 15; limestone, 70.
T. 94 N., R. 8 W. (Union).							
	Sec. 10	250					Drift, 134; shale, 100; limestone, 16.
T. 94 N., R. 9 W. (Windsor).							
John Wagner	Sec. 18	46		46	Limestone	+ 2	Diameter, 6 inches.
	N. ½ NE. ¼ sec. 18.	20				+	Flows strong stream.
— Muldownay	Sec. 35	110					Water from sand under blue till.
T. 95 N., R. 7 W. (Clermont).							
Wilkes Williams	SE. ¼ sec. 24	36		25	Shale	— 10	Starts in Upper Maquoketa shale. Diameter 6 inches.
	SE. ¼ SE. ¼ sec 13.	401	40		Galena or Platteville limestone.	—390	Loess, 10; drift, 30; shales and limestones, 361. Diameter, 6½ inches.
William Garvry	SE. ¼ SE. ¼ sec. 17.	270	50	250	Limestone	—210	Hill. Yellow clay, 25; blue till, 25; residual flints, 8; blue limestone, 100; "sandrock," 40; limestone, 52; "slate," 20.
Creamery	Clermont	42	0		do		

HOWARD COUNTY

BY O. E. MEINZER.

TOPOGRAPHY AND GEOLOGY.

The greater part of Howard county shows the gently undulating Iowan drift plain, all parts of which have a competent drainage, though the streams have not yet cut deep valleys. In the northeast, however, the Iowan drift is absent and a strong erosion topography has been developed. In large areas near the western border, and especially in Jamestown township, the total thickness of glacial drift is more than 200 feet and in certain localities it is more than 300 feet; farther east it becomes much thinner, and near the northeast corner the valleys are incised in bedrock which is extensively exposed. Owing to the irregularities of the rock surface, radical differences in the thickness of the drift may be found in wells at points not far apart and at practically the same level.

In the outcrops in the northeast, Devonian limestone is seen to rest on the Maquoketa shale, and this in turn on Galena limestone. As the strata are known to dip gently toward the southwest, it is probable that the Maquoketa and Galena pass to greater depths in this direction and that the indurated limestone which is everywhere found immediately below the drift is as a rule Devonian in age.

UNDERGROUND WATER.

SOURCES.

The water supply is derived from the glacial drift and the underlying limestone formations. The bulk of the drift is impervious bowlder clay which yields no water, but at certain levels are irregular beds of porous sand or gravel, which are generally charged with water under pressure. The limestone is compact and impervious, but contains fissures and solution passages that were probably produced by preglacial weathering. These open spaces are filled with water, which is delivered freely to wells that connect with them. In the areas of deepest drift most of the wells end in sand and gravel, but elsewhere the majority enter rock. Many wells end in saturated beds of fine sand that persistently rises with the water. In such wells both water and sand should be cased out and the drilling should be carried into the limestone if necessary.

The drilled wells vary widely in depth. In the area of thick drift many good wells are less than 100 feet deep; on the other hand, wells between 200 and 300 feet deep are not uncommon. In the northeastern part of the county, where the water level is depressed by the presence of deep valleys, it may be necessary to drill several hundred feet into the rock in order to procure satisfactory supplies.

FLOWING WELLS.

In the valley of Upper Iowa river, west and north of the village of Chester, a group of 12 or more flowing wells lie near or north of the state line. They range in depth from 80 to 100 feet and are supplied from gravel beneath a layer of impervious clay. The valley has been cut slightly below the level at which the water stands in the drilled wells on the adjoining upland plain, but not deeply enough to impair the clay layer in its function as a confining bed. Hence, in wells drilled in the valley the water rises to nearly the same height as in the upland wells or slightly above the valley level, thus giving rise to flows which range from a mere dribble to 30 or 40 gallons a minute. Indeed, in several of these wells the artesian pressure is so slight that the flow is noticeably affected by changes in atmospheric pressure. A 65-foot flowing rock well was also reported southwest of Cresco in the NE. 1/4 sec. 11, T. 98 N., R. 12 W.

Wherever the drift is continuous and but little dissected it seems to play a double part, receiving the rain water and in some way transmitting it to the deeper porous deposits and eventually to the crevices of the limestone, and yet acting in general as a confining bed. Thus, if at any point in the western part of the county a hole is drilled through the dense blue bowlder clay, the underlying sand, gravel, or rock is invariably found to be filled with water, which rushes into the drill hole and rises under artesian pressure. As already stated, entirely different conditions prevail in the northeastern area, where the drift sheet is dissected and the upper pervious formations are drained into the valleys, thereby giving rise to springs, but at the same time depressing the water level far below the upland surface. This difference is well shown along Upper Iowa river as it flows from the area of deep drift into a rock valley. That the influence of the outcrops is effective as far up as Chester seems to be indicated by the fact that flowing wells are obtained in the valley above the village, but that attempts to secure them in the valley below the village have generally failed.

Enough is known in regard to the head of water from the deep beds to make it certain that flows can not be obtained by deep drilling at Cresco, Lime Springs or Chester and that the water would remain far below the surface. Even where large supplies are required it does not seem advisable to drill more than a few hundred feet into rock.

CITY AND VILLAGE SUPPLIES.

Cresco.—The public supply at Cresco (population, 2,658) is obtained from two wells drilled into rock, the one ending at a depth of 196 feet and the other at a depth of 396 feet. The waterworks include a standpipe with a rather extensive system of mains. It is estimated that about 75,000 gallons of water are consumed daily.

The Chicago, Milwaukee & St. Paul Railway well is 1,045 feet deep, and its curb is 1,298 feet above sea level. It was completed in 1878, but was abandoned because no satisfactory supply was found.

Record of strata[1] in Chicago, Milwaukee & St. Paul Railway well at Cresco.

	Thickness	Depth
	Feet	Feet
Alluvial deposit and shales	42	42
Limestone (Devonian, Maquoketa, and Galena)	494	536
Shale, gray (Decorah)	40	576
Limestone (Platteville)	25	601
Shale, calciferous, gray (Platteville)	36	637
Sandstone (Saint Peter)	65	702
Limestone (Shakopee)	115	817
Sandstone (New Richmond)	10	827
Sandstone, calciferous (Oneota)	160	987
Sandstone (Jordan)	58	1,045

[1]Based on driller's log.

WINNESHIEK COUNTY

BY W. H. NORTON.

TOPOGRAPHY.

The important topographic features of Winneshiek county are for the most part due to the deep incision of valleys in an ancient uplifted base-level of erosion now marked by the general accordance of level of the summits of the existing ridges and divides. The edges of a large number of formations, some water bearing and some dry, are thus exposed along the valley side. The maximum relief is not far from 600 feet. The Cresco-Calmar ridge rises to a height of 1,269 feet above sea level, and the high ridges north of Upper Iowa river reach a height of 1,360 feet above sea level a short distance west of Hesper. The flood plain of Upper Iowa river on the eastern boundary of the county descends to 760 feet.

The divides separating the trunk streams and those intervening between their tributary valleys are broad-shouldered, well-rounded ridges, carved by storm water into a multitude of branching and rebranching ravines. The summits of the main divides are gently rolling, but as the trunk streams are approached the incision of the deepening valleys becomes sharp and precipitous bluffs mark the outcrop of the stronger strata.

In the western part of the county the drift sheets laid down by ancient glaciers are sufficiently thick to mask in part the erosion topography and to form the gently undulating plain of Jackson, Sumner and Orleans townships, in which erosion has been least and deposition greatest.

Although the principal streams of the area have reached maturity, the valley floors have not been widened sufficiently to give them importance for agriculture or as sites for towns.

GEOLOGY.

The geologic formations, from lowest to highest, exposed to view in the county are the following:

1. The Jordan sandstone, a coarse soft sandstone, outcropping only in the eastern part of the county in small areas at the base of the bluffs along Bear and Canoe creeks. About fifty feet of the upper beds of the formation are exposed.

2. The Prairie du Chien stage, consisting of (*a*) the Oneota dolomite, a body of light buff or whitish dolomite, 150 feet thick; (*b*) the New Richmond sandstone, about 24 feet thick; and (*c*) the Shakopee dolomite, a dolomite resembling the Oneota, graduating downward by arenaceous beds into the New Richmond and ranging from 50 to 80 feet in thickness. The Prairie du Chien stage is exposed only in the northeastern parts of the county, forming the country rock over most of Highland township and the eastern part of Pleasant township and extending up the valley of the Upper Iowa as far as Freeport.

3. The Saint Peter sandstone, soft and incoherent, white (except where stained with iron by infiltrating waters), without well-defined bedding or lamination, composed of grains of clear quartz, well smoothed and rounded. The sandstone comes to the surface in a narrow belt along the bluffs of the Upper Iowa and its tributaries as far west as Freeport. The thickness of the Saint Peter in its outcrops is about 60 feet.

4. The Platteville limestone, Decorah shale, and Galena limestone. The lowest of these formations, the Platteville limestone, succeeds the Saint Peter sandstone; it includes a basal shale (the Glenwood shale of the Iowa State Survey), about 15 feet thick

and in places sandy, forming a transition bed to the Saint Peter sandstone, and an upper bed of limestone about 25 feet thick. The Platteville is overlain by the Decorah shale, a calcareous greenish shale 30 feet thick, containing interbedded limestone layers, named from its excellent exposures in the 'Dug-Way'' at Decorah. The Decorah shale is in turn overlain by the Galena limestone, about 225 feet thick, which in this county is mostly nondolomitic but which, in counties to the south and east, consists chiefly or wholly of massive dolomites. These three formations (Platteville, Decorah and Galena) form the country rock from Hesper west to the Howard county line and thence southeast to Nordness. They cap the ridges lying between Upper Iowa river and Canoe creek and those extending south of the Upper Iowa from Decorah to Washington Prairie.

5. The Maquoketa shale, which includes a lower shaly limestone 70 feet thick, a plastic blue shale 15 feet thick. dolomites and limestones 40 feet thick, and an upper blue shale 120 feet thick. The Maquoketa for the most part outcrops south and west of Upper Iowa river. It forms the bedrock over most of the southeastern townships, occupies the long spur leading from the high Calmar-Ridgeway divide to the Upper Iowa valley, and also the valley of Turkey river on the western side of this ridge.

6. The Niagaran dolomite, which occurs in a few small outliers in Washington township near the Fayette county line, with a maximum thickness of 75 feet.

7. The Devonian limestone, which forms the surface rock in Jackson and parts of Sumner, Lincoln, Orleans and Fremont townships and in a narrow belt capping the Cresco-Calmar ridge as far east as Calmar.

8. Pleistocene deposits, including drift sheets and loess. Two drift sheets have been recognized within the county. The lowest, the Kansan, is a stony clay occurring in patches chiefly on the uplands in the eastern part of the county; the upper, the Iowan, is a thin stony clay covering the western third. Between these two stony clays occurs the interglacial Buchanan gravel. The loess, a yellow loam, mantles uplands and valley slopes outside of the area of the Iowan drift and attains in places a thickness of twenty feet.

UNDERGROUND WATER.

SOURCES.

The wide range of geologic formations exposed within the county affords an unusually large number of water beds. The lowest of these is the Jordan sandstone, from which springs rise at Highlandville and elsewhere in the northeastern townships, and to which some of the deeper wells may penetrate.

The Saint Peter sandstone is entered by the deeper wells in the same townships and affords a pure and plentiful supply, although with a low head requiring a long lift.

The Galena and Platteville contain very important water beds, especially in their lower limestones, which in the Galena rest on the Decorah shale, and in the Platteville rest on the shale member to which the Iowa State Survey has given the name Glenwood. Over the eastern part of the county they furnish inexhaustible supplies under a head sufficient to bring their water close enough to the surface to be easily pumped by the wind engines commonly employed.

The limestones of the Maquoketa shale supply some springs and wells. The heavy shales of this formation are dry but serve a most useful purpose in collecting descending ground water above their impervious upper surface either in overlying limestones or in the superficial deposits of the drift.

The different drift clays with their interbedded sheets of sand and gravel and the sandy layers forming the base of the loess afford a supply often sufficient for house wells, and in the southwestern part of the county, where the drift is thickest, for stock wells also.

DISTRIBUTION.

As the water beds of the county are so numerous and the topographic relief is so great it is difficult to define any water provinces without going into extensive detail. Even the township is too large a unit to permit exact description.

In general terms it may be said that on the ridges of the north-central part of the county, from Nordness to Hesper and to the northeast corner of the county, wells find water at the base of the Galena where its waters are held by the underlying Decorah shale. Where this supply is not tapped, because the well may fail to strike a water channel, the Saint Peter sandstone, from 60 to 100 feet deeper, is the next source. Water in the Galena has a higher head than the water in the Saint Peter, rising within 70 feet of the surface or even nearer, according to the local relief. Water in the Saint Peter rises only a few feet above the water bed; its supply, however, is large.

In the extensive area underlain by the Maquoketa shale water is found in the limestones interbedded with the impervious shales of that formation. Thus at Calmar, where the drift at the Chicago, Milwaukee & St. Paul Railway roundhouse is 65 feet thick, water was found at 90 feet in limestone above the first bed of shale, and at 160 feet in limestone below the same bed of shale. Some water was also struck on the rock at 65 feet. The Maquoketa waters rise within 100 feet or less of the surface.

Exceptionally it is necessary to go for large supplies to the chief water beds of the Galena above the Decorah shale or even to the Saint Peter. First water was reached at Calmar at 520 feet, and second water at 605 feet below the surface.

On the high ground between Calmar and Decorah farm wells commonly obtain water in the upper limestones of the Maquoketa at 75 to 100 feet below the surface, the superficial clays here being from 20 to 40 feet in thickness. Water sufficient for farm wells is not now found in the drift and all wells enter rock.

On the ridges about Ossian some wells find water in the upper few feet of the country rock, but many are compelled to go several hundred feet deeper to tap the deeper limestones of the Maquoketa, and even, exceptionally, to descend to the Galena. The diversity and complexity of the conditions are illustrated within the narrow limits of the village of Ossian, where some good house wells obtained water within thirty feet of the surface; several wells go down for 100 to 300 feet; and one reaches a depth of 735 feet.

In the ravines and in the valleys of the creeks, ground water stands naturally nearer to the surface, and where the country rock is limestone, may be found in rock wells 35 to 40 feet deep.

On the plain of Iowan drift in the southwestern townships water may locally be found in glacial sands and gravels, although not infrequently it must be sought in the underlying Devonian limestones.

SPRINGS.

Winneshiek county is one of the most favored in the state in the number of its springs and in their generous supply of pure water. In the eastern part of the county springs are found along each valley and ravine, furnishing a perennial supply to the clear running creeks. The chief source is immediately above the Decorah shale. Waters descending by sink holes and through the creviced and cavernous Galena limestones are gathered into definite courses and issue in large springs where these waterways are trenched by the ravines.

Among the best known springs from this horizon are Union Springs, on the farm of Beard Brothers, west of Decorah. Strong springs issuing on both sides of a ravine unite in a swift-flowing creek a rod wide, which at one time was utilized to run a feed mill. The August temperature of the water is 47.3° F.

Mill Spring, on the side of Upper Iowa river at Decorah, is a powerful spring with an August temperature of 48°, issuing from the summit of the Decorah shale well up the steep valley side, thus giving considerable water power, which in past years has been utilized to run a saw mill. At the west of the present debouchure and about twenty feet above the river a heavy deposit of brownish soft porous travertine has been laid down by the calcareous waters. Another noteworthy spring from this horizon is Cold Spring, a few miles northwest of Bluffton.

A large cavern, which gives exit to a characteristic underground stream from the Galena limestone is situated in section 34, Glenwood township. The mouth of the cave is described as a pointed arch forty feet high and sixty feet wide.

Most notable, however, is the Decorah ice cave, formed in part by the enlargement of a master joint and in part by the creep of the massive Galena over the underlying shale. This cavern shows the peculiar phenomenon of ice forming on its walls in spring and early summer and melting in late summer and early autumn, the walls remaining dry and bare in late autumn and winter. The solution of this interesting problem throws some light on the movements of ground water in the miles of crevices in the Galena. The freezing temperature reached by the underground air in early winter is maintained until late in the summer. Moisture from the surface is sealed out by frost during the winter, but ice begins to freeze on the cold walls of the cave as soon as the ground thaws enough in spring to permit the entrance of water from above. The ice remains until after the cold dense air has slowly passed from the great labyrinth of underground passages through the opening and has been replaced by warmer air. By this time the summer is well advanced, and as the rainfall is slight the walls remain relatively dry until the freezing temperature is again reached.

Another spring horizon is at the summit of the shale forming the basal part of the Platteville limestone (Glenwood shale of Iowa State Survey), but the springs therefrom are comparatively small.

The Jordan sandstone affords springs under hydrostatic pressure where it is cut by the valley of Bear creek from Highlandville east to the county line. Owing to the local northerly dip of the strata the springs occur on the south side of the valley.

Springs issue also from the limestones of the Maquoketa, as in section 1, Jackson township.

The base of the Niagaran forms a still higher horizon, and supplies a number of springs in Washington township.

CITY AND VILLAGE SUPPLIES.

Calmar.—At Calmar (population, 849) the water works are owned by the municipality. Water is obtained from a well 364 feet deep and distributed, at a pressure of 50 pounds, from an elevated tank with a capacity of 2,000 barrels. There are 16 hydrants, one mile of mains and 75 taps.

Well No. 1 of the Chicago, Milwaukee & St. Paul Railway at Calmar has a depth of 1,223 feet and a diameter of six inches from 70 to 860 feet and five inches to bottom; no casing. The curb is 1,261 feet above sea level and the head 150 feet below the curb. The pumping cylinder, 3¾ inches in diameter, is 374 feet below curb. The tested capacity is 80 gallons a minute. The well was completed in 1880 by W. E. Swan of Andover, South Dakota.

Record of strata in deep well No. 1 at Calmar.

	Thickness	Depth
	Feet	Feet
No record	70	70
Ordovician:		
Maquoketa shale (146 feet thick; top, 1,191 feet above sea level)—		
Limestone	76	146
Shale	10	156
Limestone	35	191
Shale, gray	25	216
Galena limestone to Platteville limestone (392 feet thick; top, 1,045 feet above sea level)—		
Limestone (Galena)	305	521
Shale, green (Decorah)	47	568
Limestone (Platteville)	30	598
Shale (Platteville)	10	608
Saint Peter sandstone (67 feet thick; top, 653 feet above sea level)—		
Sandstone	67	675
Prairie du Chien stage (325 feet thick; top, 586 feet above sea level)—		
Limestone (Shakopee)	98	773
Sand and limestone mixed (New Richmond)	47	820
Limestone (Oneota)	180	1,000
Cambrian:		
Jordan sandstone (120 feet thick; top, 261 feet above sea level)—		
Sandstone	120	1,120
Saint Lawrence formation (103 feet penetrated; top, 141 feet above sea level)—		
Limestone	103	1,223

Well No. 2 of the Chicago, Milwaukee & St. Paul Railway at Calmar has a depth of 365 feet and a diameter of ten inches, cased to 66 feet. Its curb is 1,252 feet above sea level and its head 65 feet below the curb. It finds water at 65, 90 and 160 feet. The pump cylinder, 5¾ inches in diameter, is set 100 feet below surface. The tested capacity is 115 gallons a minute and the temperature 48.5° F. The well was completed in 1904 by J. F. McCarthy of Minneapolis.

The two railway wells are fifty feet apart, and while well No. 2 was being drilled the water of well No. 1 was roily.

Driller's log of deep well No. 2 at Calmar.

	Thickness	Depth
	Feet	Feet
Clay, yellow	30	30
Clay, blue	35	65
Limestone, soft	53	118
Soapstone, soft	9	127
Limestone, soft	33	160
Shale	28	188
Limestone, hard	60	248
Shale	62	310
Limestone; hard	48	358
Shale	2	360
Limestone, hard	5	365

Decorah.—Decorah (population, 3,592) is supplied from wells. The well in common use is situated in the valley of Dry Run, about 8 feet above the level of the creek. Its diameter is 15 feet and its depth 40 feet. The water bed is gravel, rock not being entered. Water stands 15 feet below the surface and is lowered 12 feet by pumping. The maximum yield is 468 gallons a minute, the water being pumped by a suction pump run by electric motor.

For emergencies there are also used eight four-inch drilled wells 30 feet deep, located on the bottoms of Upper Iowa river, about eight feet above water level and pumped by steam. The water bed is gravel and the capacity of the wells is 240 gallons a minute. Water is pumped to a reservoir and distributed under gravity pressure of 110 pounds. There are 60 hydrants and 6½ miles of mains. The consumption is 160,000 gallons daily.

The Artesian Well & Water Company's well at Decorah has a depth of 1,600 feet and a diameter of six inches. Its curb is 877 feet above sea level. It was completed in 1877. This well is reported to have struck water at about 28 feet and to have held it at that level until the drill reached a depth of 1,600 feet, when the water disappeared and the drill was lost. The contractors claimed that they were working in granite and abandoned the well. It is very improbable, however, that crystalline rock was struck at the depth mentioned. Those who observed the drilling found reason to believe that the rising water was carried off laterally through a crevice in a limestone. Certainly the normal head of the deep artesian water should give at Decorah on low ground a flow under a good head. But lateral escape would need to be guarded against, both through crevices and probably also through the Saint Peter, whose water here is under no great pressure.

The elevation at the Chicago, Rock Island & Pacific railway station at Decorah is 862 feet above sea level. The green Decorah shale outcrops in the vicinity and the Saint Peter sandstone probably lies within a few feet of the bottom of Upper Iowa river. Five or six hundred feet is an ample estimate of the distance to the Jordan sandstone and the stores of artesian water which it contains. Besides, more or less water should enter the drill hole through crevices and sandy layers of the limestones which intervene between the Saint Peter and the Jordan. To tap the aquifers of the Dresbach and earlier Cambrian sandstones, which supply the wells of McGregor, Lansing, and New Albin, a well should be sunk to about 1,200 feet below the surface.

Ossian.—At Ossian (population, 749) the well of E. V. Gilbert has a depth of 730 feet and a diameter of 8 inches to 400 feet and 6½ inches to bottom. Its curb is 1,258 feet above sea level and its head 300 feet below curb. Water comes from 680 feet and lowers 100 feet when pumped about 47 gallons per minute. The well was completed in 1903 by J. F. McCarthy, of Minneapolis.

Log of E. V. Gilbert well.

[Supplied by owner.]

	Thickness	Depth
	Feet	Feet
Surface, white limestone, blue shale, and blue rock	590	590
Sandstone, dry		590
Unreported	90	680
Sandstone, in thin layers	18	698
Sandstone, coarse	7	705
Limestone, white	25	730

The above section, showing the occurence of two sandstones at the level of the Saint Peter, is comparable with the section of the city well at Postville. The upper sandstone falls in place with the summit of the Saint Peter at both Postville and Calmar, but the second, nearly 100 feet below the top of the first, is low for the base of the Saint Peter. Unfortunately no samples nor any detailed log exist of this most interesting well.

Minor supplies.—The following table gives statistics of miscellaneous village supplies in Winneshiek county:

Village supplies in Winneshiek County.

Village	Nature of Supply	Depth	Depth to rock	Depth to water bed	Head below curb	Volume of Springs
		Feet	Feet	Feet	Feet	
Bluffton	Open wells and springs	15-50			15	Large.
Castalia	Drilled wells	175-200	60			
Canoe	Open wells and springs	15-35	35		10	Do.
Conover	Drilled wells	60-145	30		40	Large and small.
Frankville	Do.	65-200		40	80	Small.
Fort Atkinson	Wells	60		10	20	
Freeport	Open and driven wells	10-50		20-30	8	Do.
Hesper	Drilled wells	35-80	10		25	Large.
Highlandville	Springs and drilled wells	35-67	15		20	Do.
Nordness	Wells	100-300	50	175	65	Large and small.
Ossian	Bored and drilled wells and springs.	40-500	20		40	Small.
Ridgeway	Wells and cisterns	50-400		100		

WELL DATA.

The following table gives data of typical wells in Winneshiek county:

Wells in Winneshiek County.

Owner	Location	Depth	Diameter	Depth to rock	Depth to water supply	Source of Supply	Head below curb	Remarks: (Logs given in feet)
T. 100 N., R. 9 W. (Burr Oak).		Feet	In.	Feet	Feet		Feet	
Alvin Rollins	NE. ¼ sec. 14	172	6	12	160	Limestone	72	
Do.	SE. ¼ sec. 11	285	5	13	265	Saint Peter	265	
L. W. Bennett	NE. ¼ sec. 13	70	6	----	60	Gravel	40	
T. 98 N., R. 10 W. (Lincoln).								
O. O. Rue	SW. ¼ sec. 36	96	4	30	90	Limestone on shale.	26	15 feet above Turkey river.
H. L. Wernark	SW. ¼ sec. 35	60	6	----	----	Sand	----	
----	Ridgeway, at station.	80	----	45-50	----	----	----	Blue clay at 20.
----	1 mile south of Ridgeway.	101	----	40	----	----	----	
T. 99 N., R. 9 W. (Bluffton)								
John Sexton	Sec. 32	187	6	50	162	Soft rock	50	10 feet above level of Tenmile creek, 167 feet of casing. Yields 2½ gallons per minute.
T. Nelson	NW. ¼ sec. 20	276	6	40	270	Limestone	----	300 feet above Oneota river. Lowered 50 feet by pumping. Yields 4 gallons per minute. Temperature, 50 degrees F.
W. E. Hoyt	NE. ¼ sec. 28	100	6	18	95	----	64	Temperature, 48 degrees F.
T. 98 N., R. 9 W. (Madison)								
B. T. Barfoot	SE. ¼ sec. 19	108	6	30	----	----	80	
Do.	Sec. 19	200	----	33	----	----	----	
T. 100 N., R. 7 W. (Highland).								
Julius Selmes	3 miles east of Hesper.	177	6	20	147	Sandstone	147	
T. 100 N., R. 8 W. (Hesper).								
Frank Darington	4 miles southeast of Hesper.	224	6	20	194	---- do.	194	
Charles Casterton	4 miles north f Locust.	107	6	15	69	---- do.	69	

Wells in Winneshiek County—Continued

Owner	Location	Depth	Diameter	Depth to rock	Depth to water supply	Source of Supply	Head below curb	Remarks: (Logs given in feet)
T. 96 N., R. 9 W. (Washington).								
	Fort Atkinson	100	6		80		80	
T. 96 N., R. 8 W. (Military).								
Anthony Bore	Ossian	224			60			
	Do.	735		100				Yellow clay, 35; blue till, 61; yellow clay, 4; limestone; shale; limestone, 300.
Public school	Do.	134		60			15	
	NE. ¼ SE. ¼ sec. 19.	187		28				
John Collins	SW. ¼ SW. ¼ sec. 8.	198		40		Limestone	80	Water in white limestone underlying shale.
	NE. ¼ NE. ¼ sec. 3.	220		40			50	Surface clay, 40; limestone, 25; blue shale with limestone, 124; white limestone, 31.
	NE. ¼ NW. ¼ sec. 23.	396		48	370	Limestone	330	Yellow clay, 15; blue clay, 33; limestone, 22; shale (Maquoketa) with interbedded limestone layers, 115; white limestone, 211.
T. 96 N., R. 7 W. (Bloomfield).								
	SE. ¼ NE. ¼ sec. 19.	180		82				
T. 98 N., R. 8 W. (Decorah).								
O. P. Rocksvold	SW. ¼ NW. ¼ sec. 14.	508	6½	20	500	Sandstone	380	Clay, 20; limestone, 200; Saint Peter, 70; "magnesia," 90; Cambrian or Oneota, 117; Cambrian sand, 13. Water also at 175.